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IOT-BASED SUPPLY CHAIN OF FROZEN FOOD MONITORING

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Report Submitted to Fulfill the Partial Requirements for the Bachelor of Information Technology (Hons) in Internet of Things
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DECLARATION

I declare that this report is my original work and all references have been cited adequately as required by the University.

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APPROVAL PAGE

We have supervised and examined this report and verify that it meets the program and the University's requirements for the Bachelor of Information Technology (HONS) in Internet of Things.

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LIST OF ABBREVIATIONS

ADC	Analog-to-Digital Converter
C	Celsius
CSV	Comma-Separated Values
cm	Centimetre
DC	Direct Current
F	Fahrenheit
FMCG	Fast-Moving Consumer Goods
GHz	Gigahertz
GNSS	Global Navigation Satellite System
GPIO	General-Purpose Input/Output
GPS	Global Positioning System
g	Gram
Hz	Hertz
ID	Identification
IDE	Integrated Development Environment
IoT	Internet of Things
kfg	Kilogram-force
KPIs	Key Performance Indicators
LoRa	Long Range
LTE-M	Long Term Evolution for Machines
mA	Milliampere

Mbps	Megabits per second
Mbits	Megabits
MISO	Master In Slave Out
MHz	Megahertz
mm	Millimetre
MOSI	Master Out Slave In
MQTT	Message Queuing Telemetry Transport
µs	Microseconds
QR	Quick Response
RFID	Radio-Frequency Identification
RTAD	Real-Time Anomaly Detection
s	Seconds
SDA	Serial Data
SCK	Serial Clock
SCM	Supply Chain Management
SPI	Serial Peripheral Interface
SQL	Structured Query Language
UART	Universal Asynchronous Receiver-Transmitter
V	Volt
Wi-Fi	Wireless Fidelity

ABSTRACT

This thesis presents the development of a supply chain monitoring and management system using IoT technology to address challenges in supply chain logistics. The project aimed to implement a prototype capable of real-time monitoring and control of various parameters. The research methodology involved designing and implementing the system prototype to resemble a supply container or transportation truck with installed sensors controlled by a microcontroller. The main components include temperature sensors (AHT20), RFID reader for access control, GPS module for location tracking, and a web/mobile dashboard for remote monitoring. Additionally, a robust database system was developed to store sensor readings and transaction history, ensuring data integrity and facilitating seamless communication between components for real-time data transmission.

Key findings indicate that the system effectively monitors temperature, manages access control through RFID authentication, tracks real-time location via GPS, and provides a user-friendly dashboard interface for data visualization. However, limitations such as dependency on stable WiFi connectivity and the need for periodic maintenance were identified.

The advantages of the system include enhanced supply chain visibility, improved temperature monitoring for perishable goods, and efficient access control. Despite the limitations, the system demonstrates promising potential for optimizing supply chain operations, particularly in the frozen food industry.

CHAPTER 1: INTRODUCTION

1.1 Introduction

The Internet of Things (IoT) has transformed numerous industries, and its potential in temperature-sensitive logistics is particularly significant. The IoT-Based Supply Chain of Frozen Food Monitoring project aims to address the challenge of maintaining the quality and safety of frozen products throughout the supply chain. With the increasing demand for frozen food, ensuring product integrity from production to consumption becomes crucial. This project introduces an innovative monitoring solution that leverages IoT technology to seamlessly track frozen food across the supply chain.

Moving beyond traditional tracking methods, the system provides real-time monitoring and optimization capabilities to ensure the integrity of frozen goods. By focusing on temperature-sensitive logistics, the project directly tackles critical challenges related to transporting and storing perishable products. The primary objective is to develop an efficient system that enhances operational efficiency and significantly reduces costs associated with spoilage and wastage due to inadequate monitoring.

1.2 Problem statement

- Existing poor monitoring systems lead to temperature fluctuations and quality issues, posing risks to consumers.
- Lack of immediate awareness regarding product condition throughout the supply chain.
- Delay in proactive decision-making due to the absence of timely, data-driven information in managing temperature-sensitive logistics

These problems underscore the need for a comprehensive solution that addresses monitoring gaps, improves real-time tracking, provides actionable data insights, and ensures product quality.

1.3 Objectives

- To develop an IoT monitoring system for temperature, location tracking, and access status throughout the frozen food supply chain.
- To create a real-time dashboard designed for stakeholders, providing instant access to crucial data related to temperature, location tracking, and access status.
- To enhance product security by implementing measures within the IoT-based monitoring system to restrict access to authorized personnel.

1.4 Significance of research

Research is crucial for understanding existing challenges in the frozen food supply chain and guiding solutions to enhance operational efficiency. It aids in integrating the latest IoT technologies, exploring innovative approaches, and ensuring compliance with industry regulations. Research also facilitates user-centric system design, identifies cost-effective technologies, and ensures long-term sustainability.

1.5 Project scope

- Sensor Deployment:
  Installation of sensors at critical points in the frozen food supply chain to monitor temperature, location, and access status.
- Real-time Dashboard:
  Development of a dashboard for stakeholders to access vital insights for effective management.
- Data Management and Analysis:

Establishment of a database for comprehensive data storage, analysis, and future insights.

This project aims to create an effective and sustainable IoT-based supply chain monitoring system for frozen food, contributing to enhanced product quality, safety, and efficiency throughout the supply chain.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature surrounding IoT applications in supply chain management is explored, with a specific focus on cold chain logistics and the monitoring of frozen food. An overview of existing research and insights relevant to IoT-Based Supply Chain of Frozen Food Monitoring is provided. The importance of frozen food monitoring in supply chain management is discussed, followed by an exploration of challenges and solutions in implementing IoT for this purpose. Next, the role of data analytics in enhancing decision-making in frozen food logistics is examined. Finally, technical frameworks and implementations of existing projects in this domain are discussed.

2.2 Importance of frozen food monitoring

Freezing is a common method used to preserve food, but challenges such as temperature fluctuations during storage can affect flavour, quality, and safety, as highlighted by Yahya et al. (2016). Temperature control throughout the supply chain is crucial to minimize the growth of harmful bacteria and the risk of foodborne illnesses. Different foods require precise temperature control, emphasizing the importance of maintaining temperatures during production, storage, transport, and sale.

2.3 Challenges and solutions in implementing IoT for frozen food monitoring

De Vass et al. (2021) discuss the broad applicability of IoT in Supply Chain Management (SCM) but remark on challenges including lack of awareness, integration difficulties, and security concerns. Despite challenges, IoT creates opportunities such as real-time visibility of product movement. Real-world studies are needed to understand IoT's benefits fully. Addressing challenges like security and interoperability is crucial for successful implementation, as Industry 4.0 promotes IoT integration.

2.4 Data analytics and decision-making in frozen food logistics

Nozari et al. (2021) emphasize the crucial role of big data analytics in enhancing decision-making in the FMCG industry supply chain, including frozen food logistics. Big data empowers customers, optimizes production, and ensures efficient delivery. Analyzing logistical data enhances decision-making power and allows diverse marketing strategies. Incorporating big data analytics is essential for optimizing performance and ensuring transparency.

2.5 Technical framework and implementation of existing projects

Qian et al. (2022) outline the technical implementation of a cold chain monitoring system using LoRa for data transmission and blockchain for safety information. Gillespie et al. (2023) introduce an RTAD system for real-time monitoring, employing LTE-M communication and IoT architecture. Phase, A., & Mhetre, N. (2018) propose a sensory infrastructure for real-time monitoring using various sensors and cloud-based data processing.

This transition from challenges and solutions to data analytics highlights the importance of leveraging IoT-generated data for informed decision-making in frozen food logistics.

Overall, these studies provide insights into the challenges, solutions, and technical implementations in IoT-based supply chain management, laying the groundwork for our proposed project on IoT-Based Supply Chain of Frozen Food Monitoring.

2.6 Comparison of previous projects and proposed project

The proposed project, IoT-Based Supply Chain of Frozen Food Monitoring, aims to significantly enhance the efficiency and reliability of frozen food logistics through advanced IoT integration. This system focuses on real-time monitoring, precise location tracking, secure access control, efficient data communication and management, as well as product traceability through QR code scanning. Utilizing a robust framework that includes temperature sensors, GPS, RFID, QR scanner, MQTT protocol, and cloud storage, the proposed system ensures comprehensive data analytics, timely decision-making, and enhanced traceability. The overall goal is to optimize supply chain operations, maintain product quality, ensure food safety, and improve transparency.

Aspect	Previous Projects	IoT-Based Supply Chain of Frozen Food Monitoring
Integration	Various devices and protocols for monitoring and data collection.	IoT integration with temperature sensors, GPS, RFID, and QR scanner for comprehensive real-time monitoring, control, and product traceability.
Data Transmission	LTE-M and LoRa for data transmission.	MQTT protocol for efficient and reliable data communication.
Data Management	PostgreSQL and Microsoft SQL Server are used for data storage and synchronization.	Cloud storage powered by Google for scalable and reliable data management
Data Visualization	Dashboards and platforms like Whysor for real-time data visualization.	Web and mobile dashboards powered by Node-RED for streamlined data visualization and management, enhancing accessibility and operational insights.
Real-Time Monitoring	Environmental parameters are monitored with sensors for real-time data capture and anomaly detection.	Continuous real-time monitoring with immediate data injection into the database for detailed analytics and timely alerts.
Traceability	Basic traceability functions utilizing blockchain for data credibility and traceability.	Comprehensive traceability system incorporating RFID and QR scanning for detailed product tracking and supply chain transparency.

Table 1: Comparison of previous projects and proposed project.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter explores the methodology applied in the IoT-Based Supply Chain of Frozen Food Monitoring project, outlining the systematic approach used to address research questions and achieve project objectives. It provides a concise overview of the research design, data collection methods, and analytical techniques utilized in the investigation, introducing the framework for a detailed exploration in the following sections.

3.2 Project architecture

This section outlines the overall structure of the project, detailing the various flowcharts and diagrams used to design and implement the system.

3.2.1 Project flowchart

The project flowchart provides a sequential representation of the key stages and milestones in the development of the IoT-Based Supply Chain of Frozen Food Monitoring system.

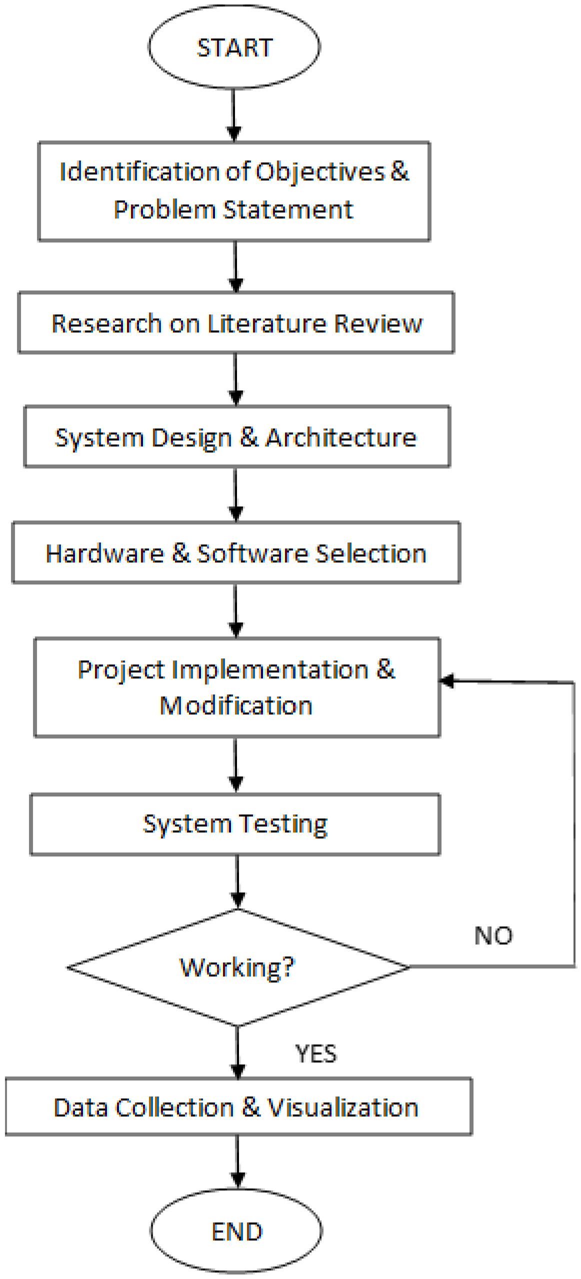


Figure 1: Project flowchart

- Identification of Objectives & Problem Statement:

Objectives and the problem statement are identified and outlined. This phase is essential for setting the project's direction and understanding the challenges that need to be addressed.

- Research on Literature Review:

A comprehensive literature review is conducted to understand existing solutions, challenges, and best practices in the field of IoT applications in supply chain management, particularly within the frozen food domain.

- System Design & Architecture:

The system is designed, and its architecture is outlined. This involves planning the integration of components such as sensors, microcontrollers, and databases, aligning with the project's objectives.

- Hardware & Software Selection:

Based on the system design, the appropriate hardware components and software tools are selected. This step is critical for ensuring compatibility and optimal performance.

- Project Implementation & Modification:

The actual implementation of the project takes place, where the selected hardware and software are integrated. As the implementation progresses, modifications may be made to enhance system efficiency or address unforeseen challenges.

- System Testing:

Comprehensive testing is conducted to validate the functionality of the IoT-based system. Troubleshooting is performed to identify and rectify any issues that arise during the testing phase.

- Data Collection & Analysis:

With the system in operation, data collection begins. The collected data is then visualized through dashboards, providing stakeholders with real-time insights into the frozen food supply chain.

3.2.2 Block diagram

The block diagram illustrates the key components of the IoT-Based Supply Chain of Frozen Food Monitoring system and their interconnections.

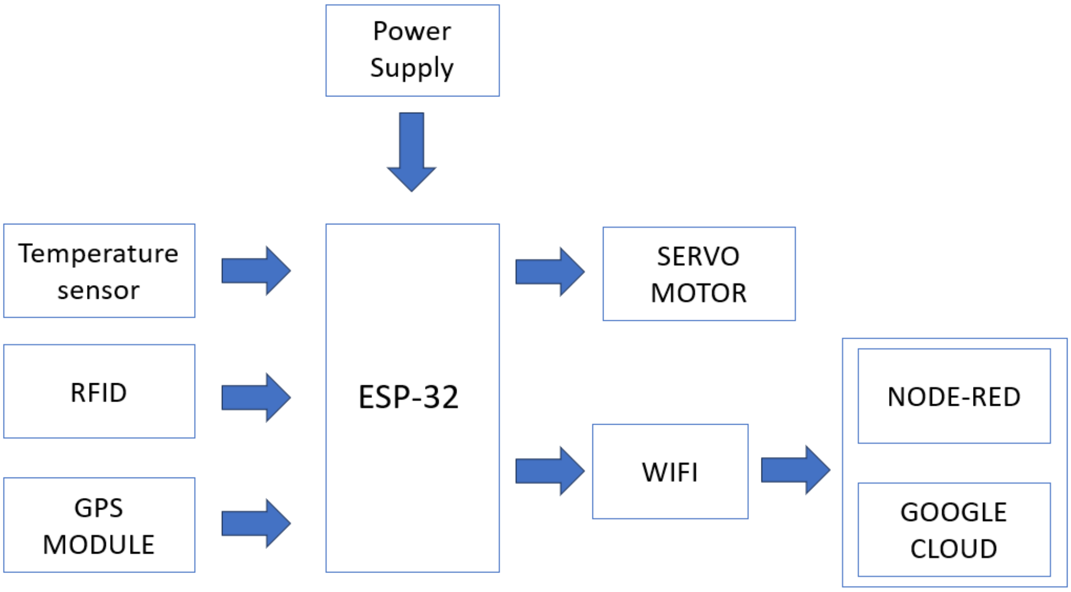


Figure 2: Block diagram

- Temperature Sensor:

This component plays a vital role in monitoring the temperature of frozen food throughout the supply chain. It provides real-time data on the environmental conditions to ensure that the prescribed temperature levels are maintained, thus safeguarding the quality and safety of frozen products.

- RFID (Radio-Frequency Identification):

The RFID module serves as a security measure to control access to the package. Only authorized suppliers with the corresponding RFID credentials can access and open the package, enhancing the security of frozen products during transportation and storage.

- GPS Module:

Location tracking is integrated through the GPS module, ensuring that the real-time location of the shipment is known. This feature aids in logistics management, allowing stakeholders to track the movement of frozen products throughout the supply chain.

- Servo Motor:

Acting as a lock/unlock mechanism triggered by the RFID module, the servo motor enhances the security of the package. It ensures that access is granted only to authorized personnel, preventing unauthorized handling of frozen food items.

- ESP32 Microcontroller:

This central processing unit controls the overall system. It is equipped with Wi-Fi capabilities, enabling real-time data transmission and remote monitoring. The ESP32 receives power from the power supply unit and manages communication between the sensors, GPS module, and RFID reader.

- Power Supply:

This unit provides the necessary electrical power to all components of the system, ensuring stable operation.

- Wi-Fi:

Enabled by the ESP32, the Wi-Fi connection facilitates real-time data updates and remote access to the dashboard, ensuring seamless communication with the server.

- Node-RED:

Serving as the dashboard interface, Node-RED provides a user-friendly platform for both end-users and suppliers. It visualizes the real-time data collected from the temperature sensor and GPS module, offering a comprehensive overview of the frozen food supply chain.

- Google Cloud:

Google Cloud services are employed for efficient and secure storage of the collected data. Google Cloud ensures robust infrastructure for data processing and storage. Essential data such as temperature records, RFID authorizations, GPS coordinates and invoice tracking are stored, facilitating data retrieval and analysis for monitoring the entire lifecycle of frozen food products.

3.2.3 System flowchart

The system flowchart illustrates the operational sequence of the IoT-Based Supply Chain of Frozen Food Monitoring system.

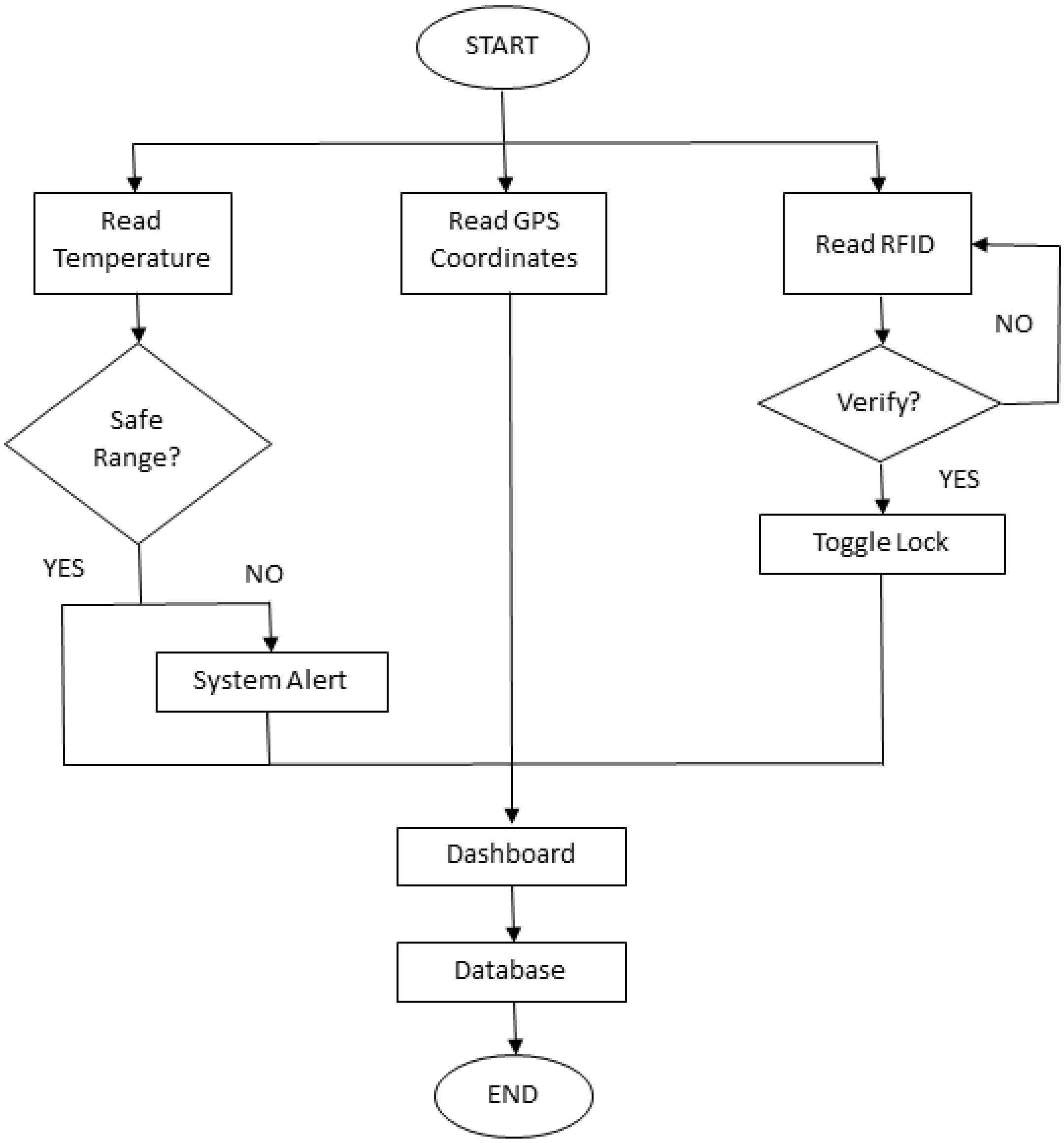


Figure 3: System flowchart

- Temperature Reading:

The system reads the temperature of the loaded products. The data is logged into the database if the temperature is within the safe range of freeze temperature. A system alert is generated and recorded in the database if the temperature falls outside the acceptable range.

- GPS Reading:

The system reads the GPS coordinates to track the real-time location of the products. The GPS data is then stored in the database for further analysis.

- RFID Verification:

The RFID module reads the RFID credentials. Once verified, the system checks the status. If the status indicates that the package is locked, the system proceeds to unlock it using the servo motor. If the status indicates that the package is already unlocked, the system locks it.

- Dashboard:

The recorded data is processed and visualized on the dashboard via Node-RED. This provides stakeholders with real-time insights into temperature conditions, location, and access status throughout the frozen food supply chain.

- Database Update:

All relevant data, including temperature readings, GPS coordinates, RFID verification status, and servo motor actions, is updated in the database for future reference and analysis.

3.2.4 Invoice tracking

The invoice tracking flowchart outlines the process of creating and managing invoices, ensuring every transaction is properly documented. This process enhances traceability, reliability, and efficiency within the supply chain.

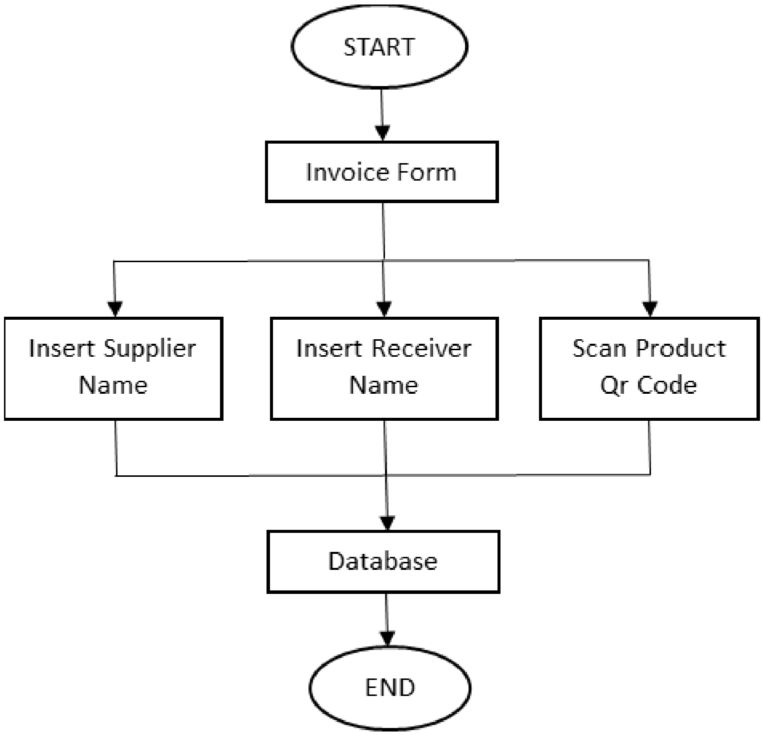


Figure 4: Invoice tracking flowchart

- Invoice Form:

The invoice form is accessible via a digital dashboard, to fill with transaction details.

- Insert Supplier Name:

To record responsible personnel in supplying frozen products.

- Insert Receiver Name:

To record responsible personnel in receiving frozen products.

- Scan Product QR Code:

The QR code on the product is scanned using any device with a QR scanner. To record specific supplying products by unique ID for traceability.

- Database:

The invoice information is updated in the database with a timestamp for future reference and analysis.

3.2.5 Data storage

The data storage flowchart illustrates the process of managing data. This process enables stakeholders to access real-time insights and historical data, enhancing decision-making and system reliability.

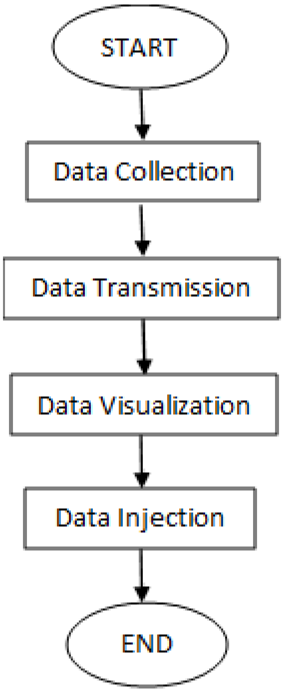


Figure 5: Data storage flowchart

- Data Collection:

Data collected from sensors, including temperature readings, GPS coordinates, and access control statuses, is processed by the ESP32 microcontroller.

- Data Transmission:

Processed data is then transmitted to Node-RED via MQTT protocol for further processing and visualization.

- Data Visualization:

Node-RED processes and visualizes the data on custom dashboards, providing real-time insights to stakeholders.

- Data Injection:

Processed data is injected into Google Cloud and Google Sheets for long-term storage and analysis.

3.3 Parameter measured

In the context of the IoT-Based Supply Chain of Frozen Food Monitoring, ensuring the quality, security, and traceability of frozen food products relies on measuring critical parameters, namely temperature, location, and access status. The thoughtful selection of hardware components, including temperature sensors, GPS modules, and RFID systems, is important in achieving project objectives. This section provides a detailed examination of the technical decisions made for measuring and monitoring these crucial parameters, establishing the foundation for subsequent implementation and testing phases.

3.3.1 Temperature measurement system

Maintaining an optimal temperature range is crucial for preserving the quality and safety of frozen food products throughout the supply chain. The recommended temperature range for storing and transporting frozen food is typically set between -18°C (0°F) and -23°C (-10°F). Adhering to this temperature range ensures that frozen products remain in a frozen state, preventing the growth of harmful microorganisms and maintaining the desired texture, flavour, and nutritional value.

If the temperature reading deviates beyond the specified range, triggering a condition where it exceeds -18°C, an immediate system alert is generated. This alert serves as a critical notification to stakeholders, indicating a potential compromise in the preservation of frozen products. The system captures and logs this alert in the database, allowing for prompt corrective actions to be taken, such as adjusting the temperature settings or addressing any issues that may impact the temperature control system.

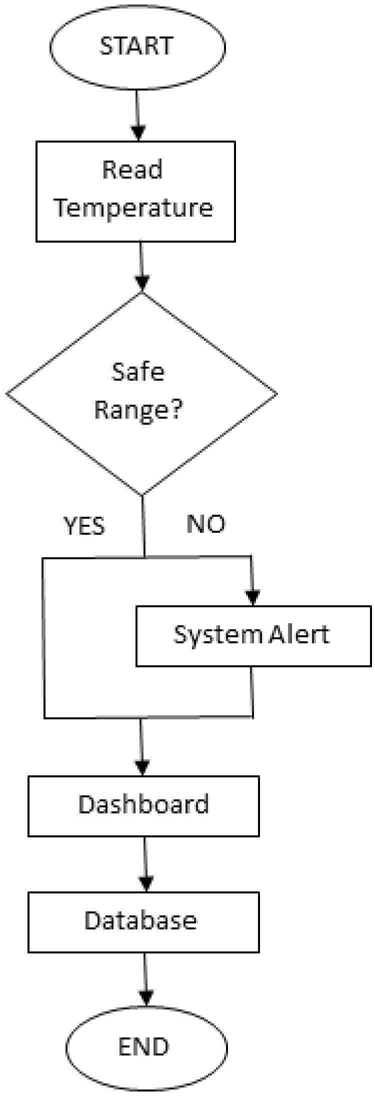


Figure 6: Flowchart of temperature measurement system

3.3.1 Temperature sensor module

The AHT20 temperature sensor has been selected for its precision and reliability in measuring temperature. The AHT20 is a high-precision digital temperature sensor specifically designed for applications requiring accurate temperature measurements, making it suitable for monitoring frozen food conditions within the supply chain. The sensor is compact, lightweight, and integrates seamlessly into the IoT system. (Guangzhou Aosong Electronic Co., 2020)

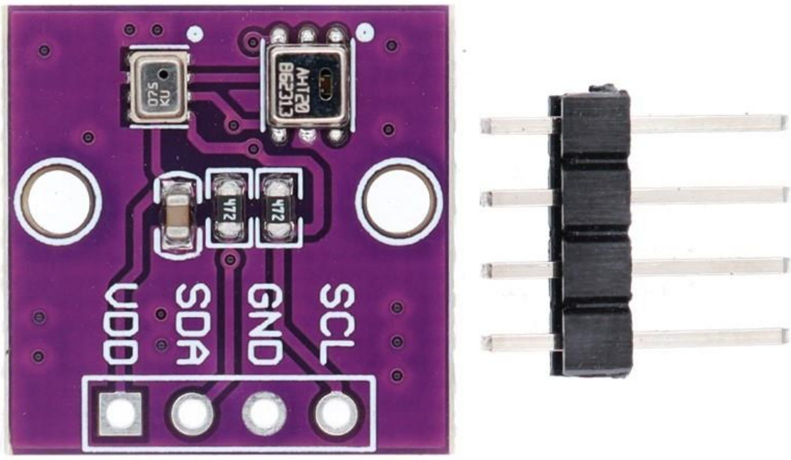


Figure 7: AHT20 temperature sensor

The AHT20 sensor employs a thermocouple-based temperature sensing mechanism. It utilizes a thin-film capacitor to measure changes in capacitance, which are directly proportional to variations in temperature. This capacitive measurement method ensures high accuracy and responsiveness, making the AHT20 an ideal choice for applications where precise temperature monitoring is critical (Guangzhou Aosong Electronic Co., 2020). The digital output from the sensor is interfaced with the ESP32 microcontroller in the system architecture. This integration allows real-time temperature data to be collected and further processed for analysis and visualization.

Supply voltage	2.2 - 5.5V
Measuring range	-40 ~ + 85 ℃
Temperature accuracy	± 0.3 ℃
Resolution	0.01℃
Response time	5s
Output signal	I^2C signal
Weight	4 g
Dimensions	10x20 mm

Table 2: AHT20 specification

3.2.2 Real-time location tracking system

Real-time location tracking is a fundamental and crucial aspect of the IoT-Based Supply Chain of Frozen Food Monitoring system for several key reasons:

- Enhanced Logistics Management:

Real-time location tracking allows for continuous monitoring and visibility of the exact whereabouts of frozen food shipments throughout the supply chain. This enhanced logistics management ensures efficient route planning, timely deliveries, and proactive response to any unexpected events or delays.

- Optimized Supply Chain Operations:

The ability to track the real-time location of frozen food products enables supply chain professionals to optimize operations. This includes identifying potential bottlenecks, streamlining transportation routes, and making data-driven decisions to enhance overall supply chain efficiency.

- Security and Risk Mitigation:

Tracking the location of frozen food products in real-time adds a layer of security to the supply chain. In the event of any anomalies or deviations from the planned route, immediate alerts can be generated, enabling rapid response to potential security threats or risks, such as theft or tampering.

- Accountability and Transparency:

Real-time location data fosters accountability and transparency among all stakeholders in the supply chain. It provides verifiable evidence of the movement and handling of frozen food products, promoting trust and reliability among suppliers, distributors, and end-users.

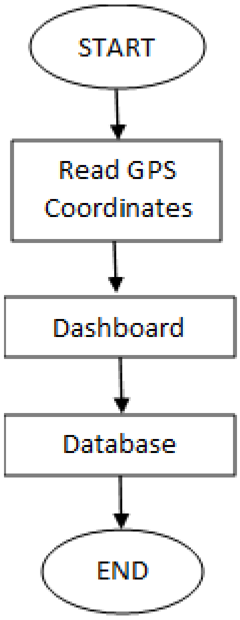


Figure 8: Location tracking system flowchart

3.2.2.1 GPS module

The NEO-6M GPS module has been selected as a key component in the IoT-Based Supply Chain of Frozen Food Monitoring system for its reliable and accurate real-time location tracking capabilities. The NEO-6M is a compact and cost-effective GPS module for applications requiring precise location data.

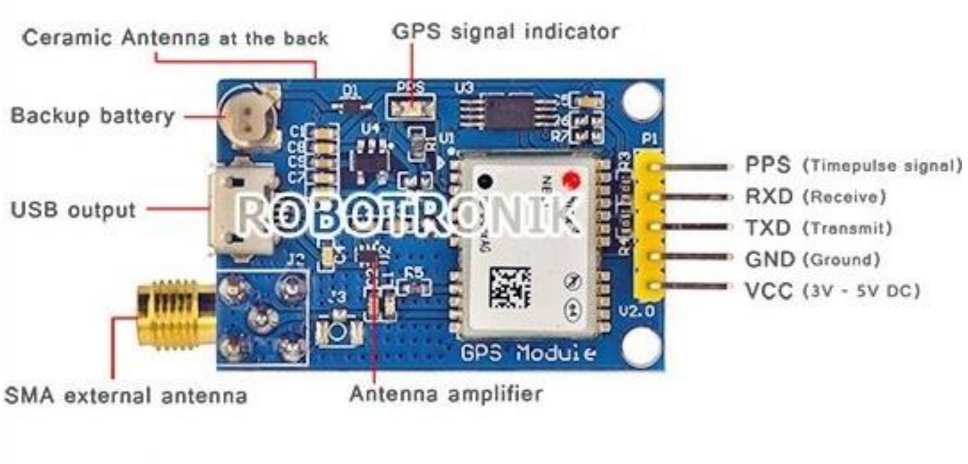


Figure 9: NEO-6M GPS

The NEO-6M GPS module operates based on the Global Navigation Satellite System (GNSS), utilizing signals from multiple satellites to determine the device's precise location. The working principle involves:

- Satellite Reception:

The module receives signals from satellites orbiting the Earth. The NEO-6M is capable of connecting to both GPS and GNSS satellites, enhancing its accuracy and reliability. (Das D, 2022)

- Trilateration:

The module calculates its position by trilateration of the signals received from at least three satellites. Trilateration involves determining the intersection point of spheres created by the distance measurements from each satellite. (LastMinuteEngineers, n.d.)

- Data Processing:

The GPS module processes the received signals and computes the latitude, longitude, altitude, and time information. This data is then transmitted to the microcontroller for further processing and integration into the overall system. (Das D, 2022)

Supply voltage	3.3V - 5V DC
Operating current	45mA
Baud rates	9600 (configurable from 4800 to 115200)
Navigation update rate	5Hz maximum (1HZ default)
Capture time	Cool start: 27s (fastest) Hot start: 1s
Operating temperature range	-40 to +85°C
Separated	18 X 18mm GPS antenna
Dimension	22 X 30 X 13mm
Weight	19g

Table 3: NEO-6m GPS module specifications

3.3.3 Access status monitoring system

The Access Status Monitoring System employs RFID technology to enhance security by controlling access to the packages. Only authorized suppliers possessing the corresponding RFID credentials are granted access to open the package. The system utilizes a servo motor as a lock/unlock mechanism, responding to signals from the RFID module.

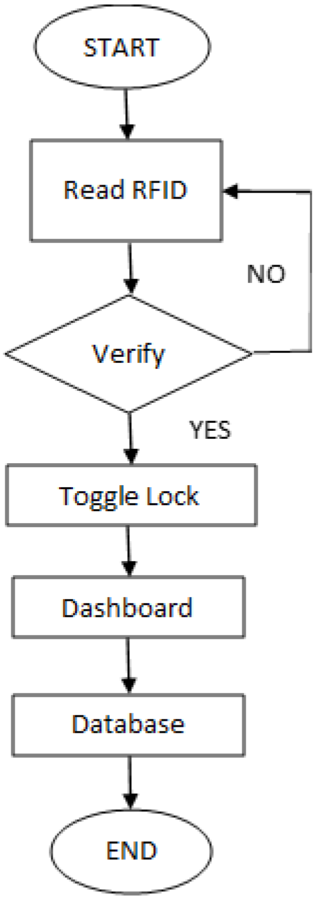


Figure 10: Access status monitoring system flowchart

The RFID module reads the RFID credentials provided by suppliers attempting to access the package. Once RFID verification is successful, the system checks the status of the package. If the status indicates that the package is locked, the system proceeds to unlock it using the servo motor. Conversely, if the status reveals that the package is already unlocked, the system initiates the locking mechanism. This mechanism is a crucial layer of security in controlling package access. Every access attempt, successful verifications, and any changes in the lock/unlock status are monitored, and the corresponding data is stored in the database to ensure a detailed audit trail.

3.3.3.1 RFID module

The RC522 is a popular RFID reader and writer module that provides a cost-effective solution for RFID-based access control. Widely used in various applications, it is specifically chosen for its reliability, ease of integration, and compatibility with microcontrollers.

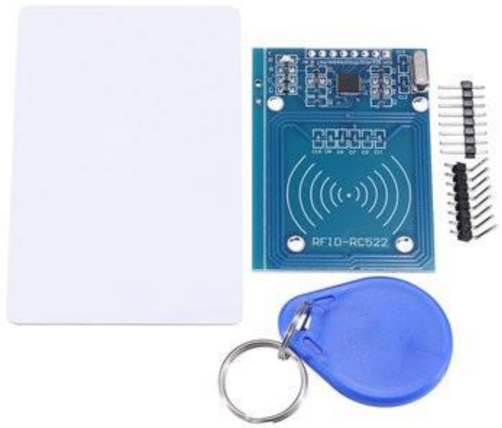


Figure 11: RFID RC522

The RC522 RFID module operates based on Radio-Frequency Identification (RFID) technology. As explained by LastMinuteEngineers (n.d.), the working principle involves:

- RFID Tags and Cards:

Authorized suppliers are provided with RFID tags or cards containing unique identification information. These tags or cards are associated with the supplier's credentials.

- Reader and Antenna:

The RC522 module consists of a reader and an antenna. When a tagged item or card is brought into proximity with the antenna, it energizes the RFID tag, allowing it to transmit its unique identifier. Shahid, M. (2022).

- Data Transmission:

The module reads the transmitted data from the RFID tag and sends it to the connected microcontroller, in this case, the ESP32, for further processing.

- Verification and Access Control:

The microcontroller verifies the received RFID data against the authorized credentials stored in the system. If the verification is successful, access is granted.

Working current	13—26mA/ DC 3.3V
Working frequency	13.56MHz
Card reading distance	0～60mm（mifare1 card）
Protocol	SPI
Data communication speed	Maximum 10Mbit/s
Card types supported	Mifare1 S50, Mifare1 S70, Mifare UltraLight, Mifare Pro, Mifare Desfire
Dimension	40mm×60mm
Max SPI speed	10Mbit/s

Table 4: RFID RC522 specifications

3.3.3.2 Servo motor module

The Tower Pro 9g SG90 servo motor is a critical component in the Access Status Monitoring System of the IoT-Based Supply Chain of Frozen Food Monitoring. The Tower Pro 9g SG90 is a widely used micro servo motor known for its compact size, lightweight design, affordability and versatility (Sawkare R, 2020).

Figure 12: Tower Pro 9g SG90 servo motor

The servo motor receives a control signal from the microcontroller, which determines the desired position or angle of rotation. It consists of a DC motor, a set of gears, and a feedback potentiometer. The DC motor, installed with the bolt lock of the container/transportation, acts as a safety mechanism. Gears amplify the rotational movement of the DC motor to achieve precise control, while the potentiometer continuously provides feedback on the motor shaft's current position (Sawkare R, 2020). This feedback loop ensures that the motor adjusts its position until the desired angle is reached. The output shaft of the servo motor rotates to the specified angle based on the control signal received, enabling the locking or unlocking of the package.

Operating Voltage	4.8 V (~5V)
Operating speed	0.1 s/60 degree (Total 180 degree)
Weight	9 g
Dimension	22.2 x 11.8 x 31 mm approx.
Stall torque	1.8 kgf·cm
Dead band width	10 μs

Table 5: Tower Pro 9g SG90 servo motor specifications

3.4 Microcontroller

The ESP-WROOM-32 microcontroller is a crucial element in the architecture of the IoT-Based Supply Chain of Frozen Food Monitoring system. As the central processing unit, it coordinates the functions of various modules, sensors, and actuators within the system. It belongs to the ESP32 series and is selected for its dual-core processing capabilities, low power consumption, and built-in Wi-Fi and Bluetooth connectivity (Elprocus, 2019).

Figure 13: ESP-WROOM-32

The microcontroller features two processing cores, allowing for parallel execution of tasks and improved overall system performance. Integrated Wi-Fi and Bluetooth capabilities enable seamless communication with other devices and networks. The ESP-WROOM-32 is designed for energy efficiency, making it suitable for battery-powered applications. It comes equipped with a variety of peripherals, including GPIO pins, I2C, SPI, UART, analog-to-digital converters, and more, providing flexibility for interfacing with sensors and actuators (Elprocus, 2019).

Bandwidth	72 MHz
Data Rate	150 Mbps
Interface	Ethernet, I2C, I2S, SPI, UART
Max Frequency	2.484 GHz
Max Operating Temperature	85 °C
Max Supply Voltage	3.6 V
Min Operating Temperature	-40 °C
Min Supply Voltage	3 V
Nominal Supply Current	500 mA
Number of ADC Channels	16
Number of GPIO	32

Table 6: ESP-WROOM-32 specifications

3.5 Programming software

The programming software component of the IoT-Based Supply Chain of Frozen Food Monitoring system is a critical element that enables the seamless integration and operation of hardware components, data processing, and communication.

3.5.1 Arduino IDE

Arduino IDE (Integrated Development Environment) is a vital software component in the IoT-Based Supply Chain of Frozen Food Monitoring system, serving as the programming platform for the ESP-WROOM-32 microcontroller. Arduino IDE is an open-source software application that provides a user-friendly environment for writing, compiling, and uploading code to Arduino-compatible microcontrollers.

Figure 14: Arduino IDE

The IDE features a text editor for writing and editing code. It supports various programming languages, primarily focusing on the Arduino programming language based on C/C++. Arduino IDE includes a built-in compiler that translates the written code into machine-readable instructions for the microcontroller. It provides a straightforward mechanism for uploading compiled code to the ESP-WROOM-32 microcontroller, enabling rapid prototyping and testing. The IDE allows easy integration of external libraries, providing pre-written code for common functions and peripherals, streamlining the development process. A crucial tool for debugging, the serial monitor allows real-time communication between the microcontroller and the computer, displaying output messages and aiding in code troubleshooting (Aqeel A, 2018).

3.5.2 Node-RED

Node-RED is a fundamental software component in the IoT-Based Supply Chain of Frozen Food Monitoring system, serving as a visual programming tool for creating the system's dashboard and facilitating data flow between devices and databases. Node-RED is an open-source flow-based development tool for the visual programming of event-driven applications. It provides a browser-based interface that allows users to wire together devices, APIs, and online services (Lundberg M, 2024). In this project, Node-RED is employed to create a user-friendly dashboard, subscribe to the MQTT connection from the broker, inject data into the cloud database and manage functions of project flows.

Figure 15: Node-RED

Node-RED utilizes a flow-based programming paradigm, nodes are connected to define the flow of data and actions. The platform includes a rich library of pre-built nodes that represent different functions, services, and protocols. Users can easily drag and drop nodes onto the canvas to construct their application. Node-RED supports integration with a wide range of devices, APIs, and protocols, making it suitable for IoT applications. It enables the creation of interactive dashboards with customizable UI elements, providing a real-time view of system data. The visual interface makes it accessible to users with varying levels of programming expertise, allowing for quick and efficient development (Lundberg M, 2024).

3.6 Database management

Effective data management is essential for the IoT-Based Supply Chain of Frozen Food Monitoring system, allowing stakeholders to gain valuable insights from real-time and historical data. This section discusses the strategies for data visualization and storage implemented in the system.

3.6.1 Node-RED dashboard

Node-RED serves as the central dashboard interface, providing both web and mobile options for real-time data visualization. Utilizing a variety of nodes and functions, the dashboard is -designed to display crucial information such as temperature readings, GPS coordinates, lock status, and other relevant data points. Stakeholders can easily monitor the status of the frozen food supply chain through this intuitive dashboard interface. The web dashboard offers a comprehensive view accessible via browsers, while the mobile dashboard provides on-the-go access for users, ensuring flexibility and convenience.

3.6.2 Google Cloud

Google Cloud services, a cloud computing platform by Google, are leveraged for robust data storage and processing capabilities. With Google Cloud, the system can efficiently handle large volumes of data generated by the monitoring system. It provides a secure and reliable infrastructure that ensures data integrity throughout transmission and storage processes. Storing data in the cloud offers benefits such as scalability, allowing the system to adapt to changing data storage needs easily. Additionally, cloud storage provides redundancy and disaster recovery options, ensuring data availability and reliability. Integration with other Google services enables seamless data management and analysis, enhancing the overall efficiency of the system (Mixon & Wigmore, 2023).

Figure 16: Google Cloud

3.6.3 Google Sheets

In addition to Google Cloud, Google Sheets is utilized as a supplementary tool for data management and visualization. Google Sheets offers a familiar and user-friendly interface for stakeholders to view, analyze, and share data stored in the cloud. Stakeholders can easily collaborate and access critical information, facilitating better decision-making processes. Google Sheets enhances the accessibility of data, allowing stakeholders to interact with the information effortlessly and supporting seamless data sharing and reporting within the organization.

Figure 17: Google Sheets

3.7 Circuit diagram

The circuit diagram illustrates the integration of components in the system. The AHT20 sensor interfaces with the ESP-WROOM-32 microcontroller via its serial clock (SCL) and serial data (SDA) pins, connected to GPIO pins 22 and 21 respectively, operating at 3.3V. The RFID module connects to the microcontroller with 3.3V power, utilizing pins for reset, data input/output (MISO/MOSI), serial clock (SCK), and serial data (SDA). A 5V-powered servo motor receives control signals through pin 13. The NEO-6M GPS module communicates with the microcontroller via 5V power, using serial communication with RX (receive) on pin 17 and TX (transmit) on pin 16. This diagram provides a comprehensive overview of the hardware architecture, emphasizing connectivity and power considerations across the system.

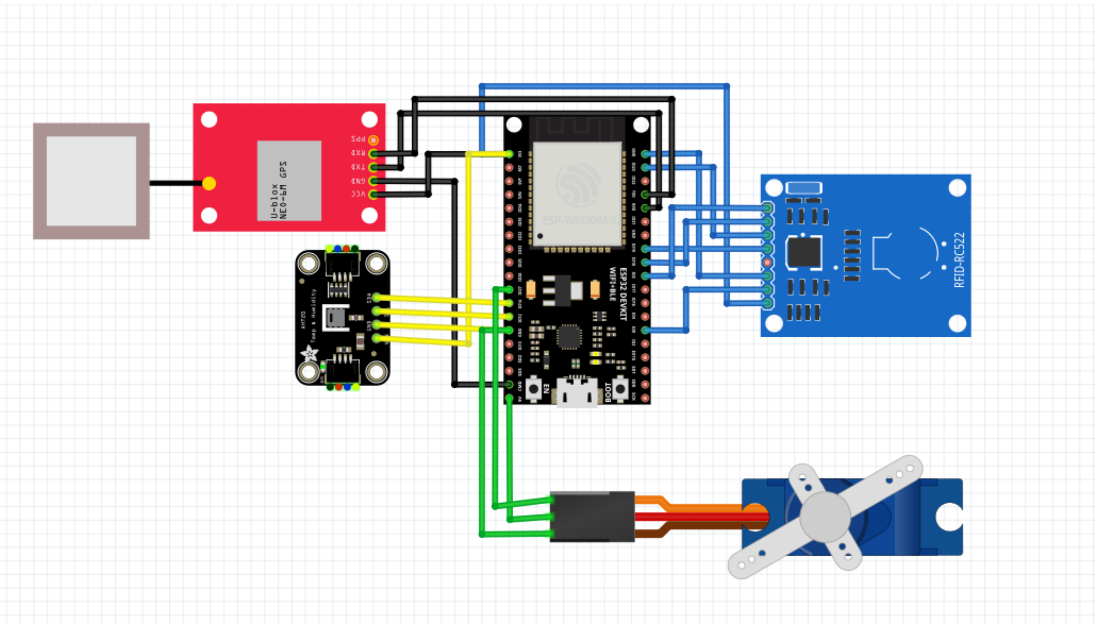


Figure 18: Circuit diagram

3.8 Project cost

The project cost section outlines the financial resources for deploying the IoT-Based Supply Chain of Frozen Food Monitoring system.

No.	Product	Price (RM)
1	ESP- WROOM-32U Development Board WiFi+Bluetooth Ultra-Low Power Consumption Dual Core	16.50
2	GY-NEO6MV2 with Flight Control EEPROM MWC APM2.5 Large Antenna	12.10
3	3.56MHz RFID Card Reader RC522 MFRC522	3.50
4	Smart Electronics Rc Mini Micro Classic servos 9g SG92R SG90 MG90S	4.70
5	AHT20 High Precision Digital Temperature and Humidity Sensor Measurement Module	3.20
6	Foam box Polystyrene box /Ice Box insulation box (Size- M)	8.90
7	Male to Male (MM) 40pcs Dupont Jumper Wire Rainbow 40p Wires Cable 30cm	4.60
8	Female to Male (FM) 40pcs Dupont Jumper Wire Rainbow Cable 40p 30cm	4.60
9	Female to Female (FF) 40pcs Dupont Jumper Wire Rainbow Cable 40P 30cm	4.60
Total		63.10

Table 7: Project cost

CHAPTER 4: RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the outcomes of the project and provides an in-depth examination of the various components developed. It begins with an overview of the system programs, followed by a detailed analysis of the project prototype, highlighting the installation of sensors and microcontrollers. The features of the dashboard are then explored, covering both the web and mobile interfaces, temperature monitoring with alert systems, lock state notifications, and location tracking capabilities. Additionally, the invoice management system is discussed, with a focus on product QR scanning. The chapter concludes with an analysis of the system database configurations, detailing their structures and roles within the project.

4.2 System programs

The system programs detail the operational workflow of the IoT-Based Supply Chain of Frozen Food Monitoring. It provides a comprehensive analysis of the stages and decision points involved in the system's operation, programmed using the Arduino IDE and written in C++.

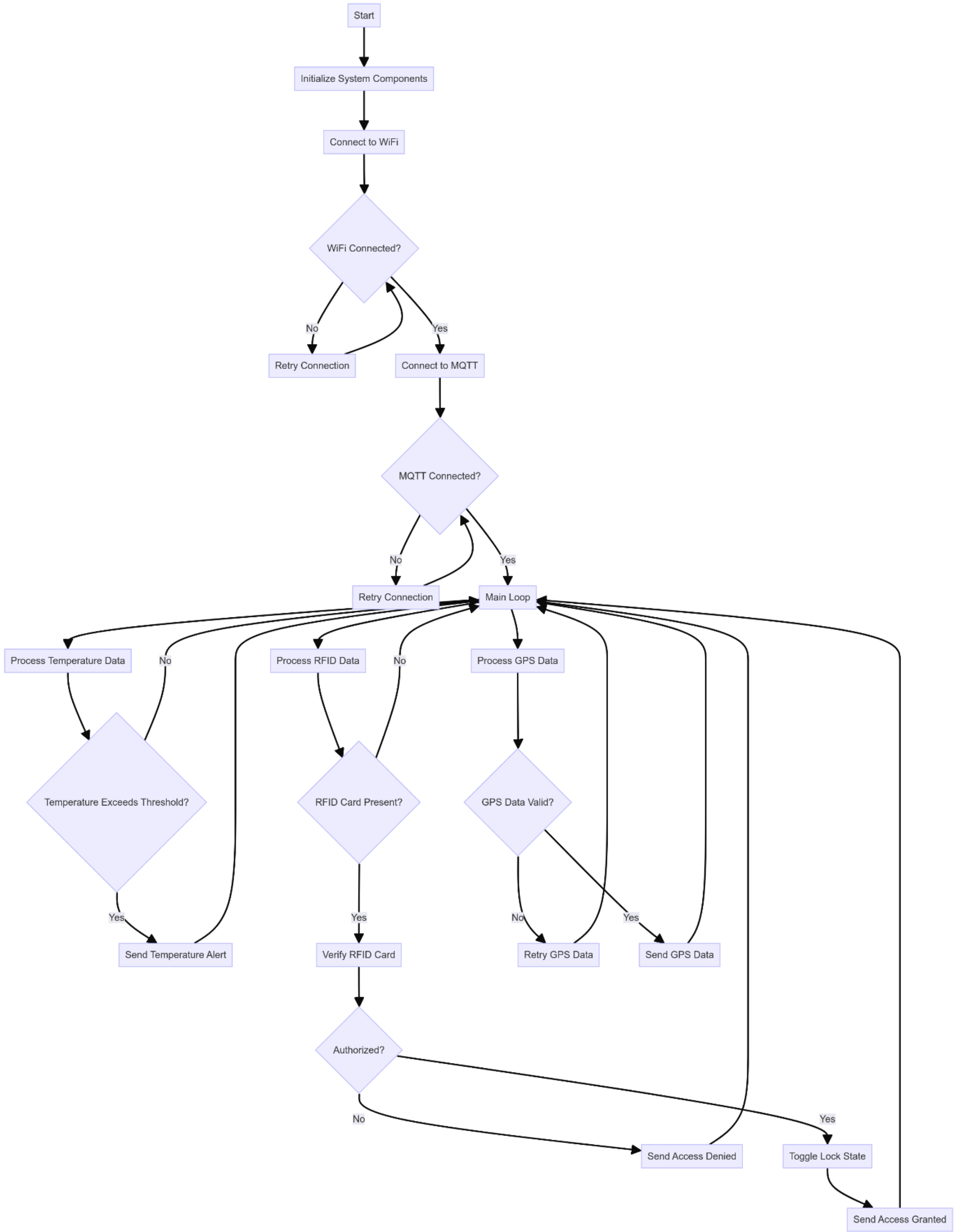


Figure 19: System programs flowchart

The system initialization begins by setting up all necessary components and attempting to establish a Wi-Fi connection for data transmission. This phase involves initializing hardware and software components, such as sensors and communication modules. Once initialized, the system tries to connect to a Wi-Fi network. If successful, it proceeds to connect to the MQTT broker, which is essential for messaging between devices and the central server. In case of a failed Wi-Fi connection, the system retries until a connection is established, ensuring continuous operation.

Following a successful Wi-Fi connection, the system attempts to establish communication with the MQTT broker. MQTT (Message Queuing Telemetry Transport) is used for efficient messaging between devices and the central server. This step involves establishing a connection with the MQTT broker, which acts as a communication intermediary. If the MQTT connection is successful, the system proceeds to the main operational loop. However, if the connection fails, the system retries the connection process to ensure reliable communication.

The main operational loop constitutes the core functionalities of the monitoring system. It involves processing temperature, RFID, and GPS data to ensure effective monitoring of the supply chain. Each iteration of the loop includes specific checks and actions. Temperature data is monitored to detect threshold exceedances and trigger alerts if necessary. RFID data is processed to verify access authorization and toggle the lock state accordingly. GPS data is checked for validity and sent to the central system for tracking. These processes ensure continuous monitoring and control of critical parameters throughout the supply chain journey.

4.2 Project prototype

The project prototype consists of an icebox modified to resemble a supply container or transportation, making it suitable for supply chain simulation. Sensors and a microcontroller are installed within the prototype to achieve the project objectives.

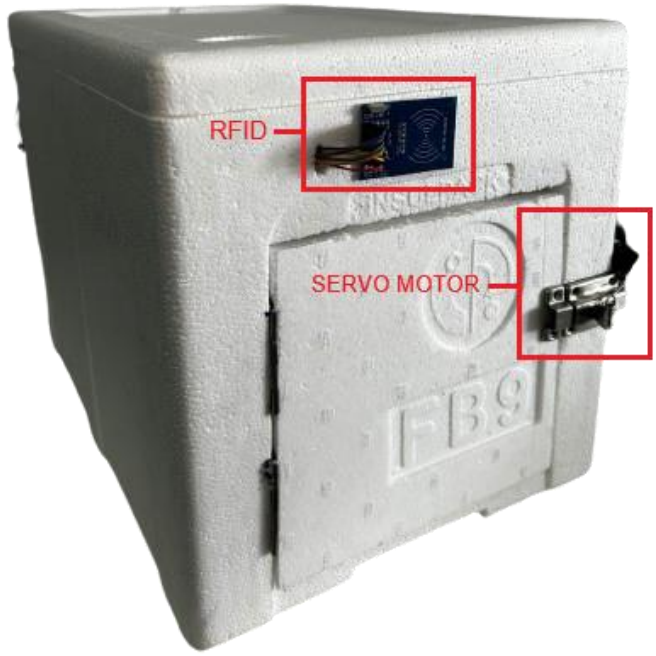


Figure 20: Prototype front view

The RFID reader is installed above the door for access control. A servo motor and door lock mechanism are installed on the side of the icebox, allowing the door to lock and unlock based on RFID access, as shown in *Figure 20*.

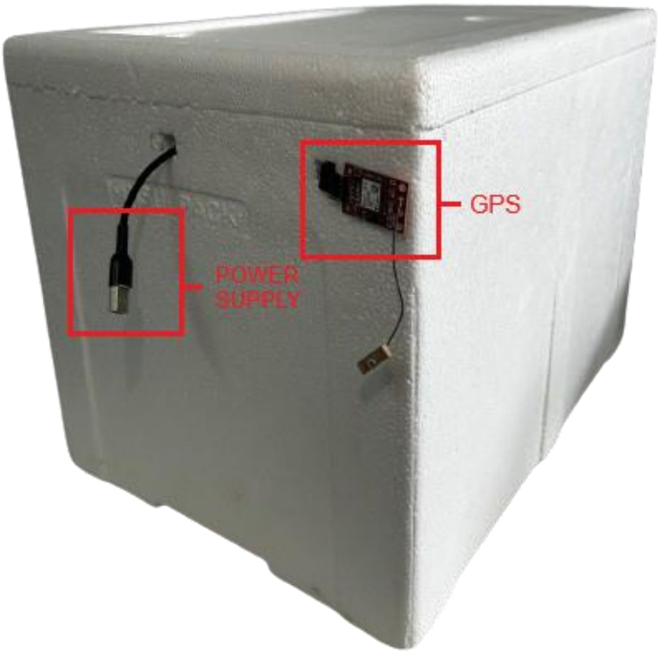


Figure 21: Prototype back view

The GPS module is installed at the back of the box for location tracking, and the power supply unit, which powers the entire system, is also located there, as shown in *Figure 21*.

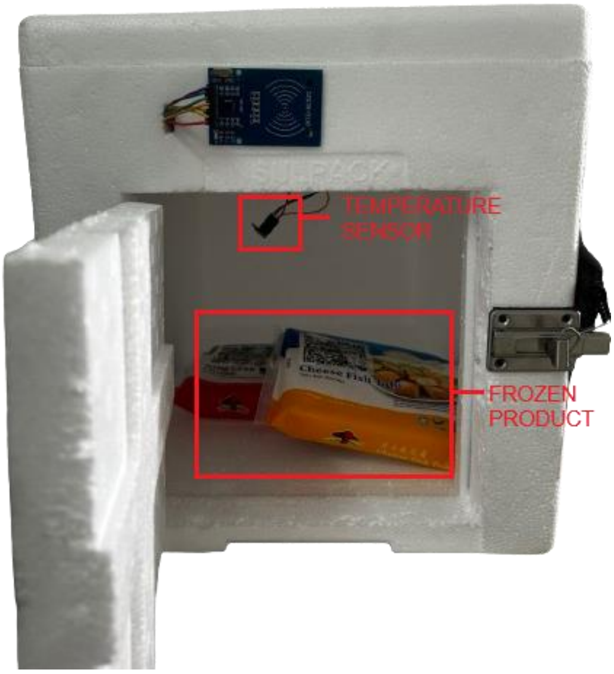


Figure 22: Prototype inside view

The AHT20 temperature sensor is installed inside the icebox to monitor temperature. Frozen products with unique ID QR codes for tracking purposes are loaded inside, as shown in *Figure 22*.

4.2.1 Registered RFID for authorized personnel

The system registers RFID cards of authorized personnel, ensuring access control within the supply chain. Each RFID card is uniquely identified and corresponds to specific personnel, such as ID cards *A-0001:ADAM*, where the unique ID is associated with the worker's name, as shown in *Figure 23*. When authorized personnel present their RFID card, the system verifies the ID against the registered database. If the ID matches an authorized user, access is granted, allowing them to interact with the system. Conversely, unrecognized RFID cards are denied access, enhancing security and control over system operations.

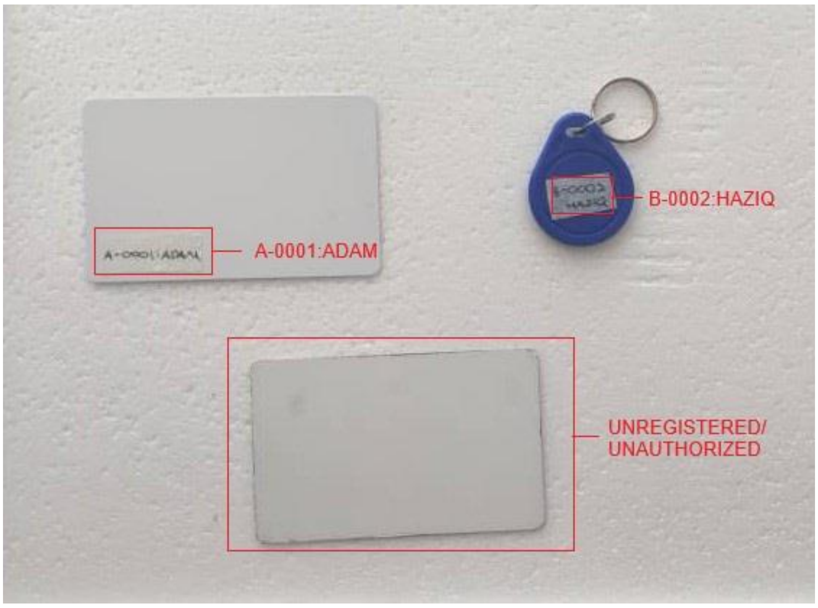


Figure 23: Registered RFIDs

4.2.2 Unique QR code identification of frozen products

Each frozen product is equipped with a unique QR code for identification and tracking purposes. The QR code is system-aligned and contains essential information about the product of a unique ID followed by the product's name, such as *FT01-FishTofu* and *CC02-CrabChunk,* as shown in *Figure 24*. This QR code serves as a crucial identifier for each product within the supply chain monitoring system, enabling accurate tracking throughout the transportation and supply process.

Figure 24: Unique QR code

4.3 Dashboard

The dashboard is a centralized interface for real-time monitoring and management of the system, providing key information and controls for stakeholders. It offers intuitive access to temperature readings, GPS coordinates, lock status, and other relevant data, both via web and mobile platforms.

4.3.1 Web dashboard

Authorized personnel can access the web dashboard through a browser interface to obtain real-time data and controls, facilitating monitoring and management of the system, as shown in *Figure 25*.

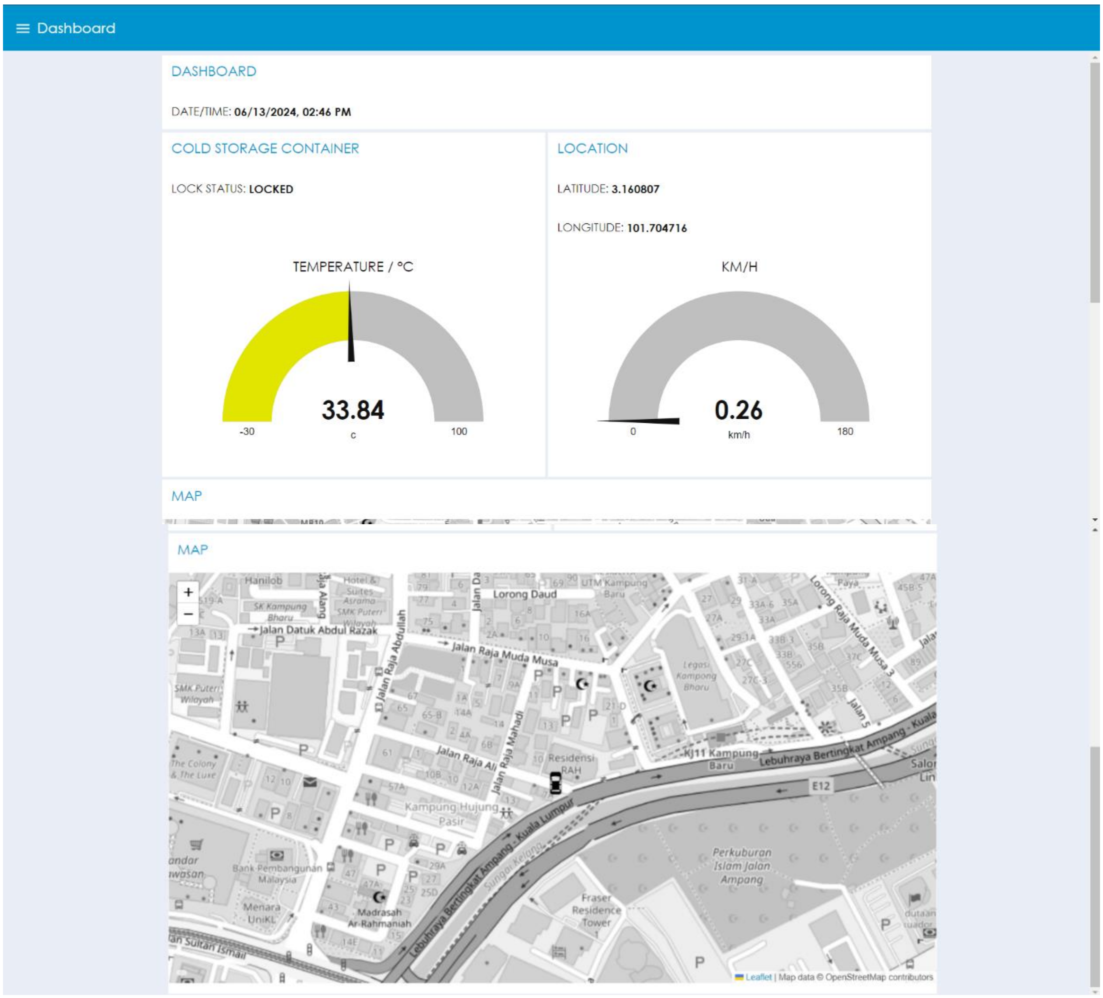


Figure 25: Web dashboard

4.3.2 Mobile dashboard

The mobile dashboard provides a streamlined, user-friendly interface for accessing system data remotely, as shown in *Figure 26*.

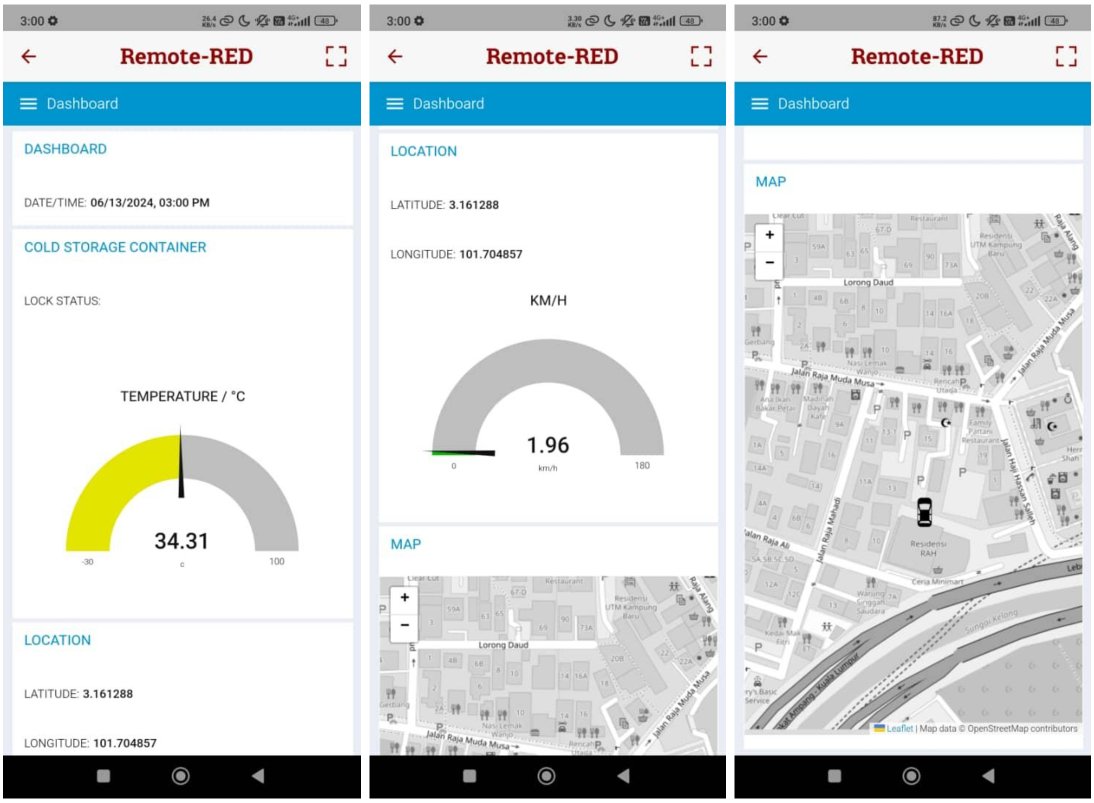


Figure 26: Mobile dashboard

4.3.3 Temperature gauge and lock status

The temperature gauge provides real-time visibility of the current temperature inside the container, allowing users to monitor temperature conditions effectively. It offers instant feedback on temperature variations, ensuring that the frozen products are stored within the desired range. Additionally, the lock state section indicates the status of the container lock, providing information on whether the container is securely locked or unlocked, as shown in *Figure 27*. This feature enhances security and ensures that the contents are properly protected during transit or storage.

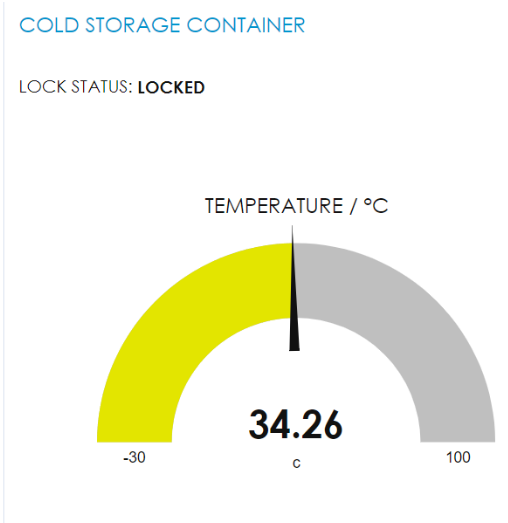


Figure 27: Temperature gauge and lock status

4.3.3.1 Alert System

The alert system plays a crucial role in notifying stakeholders of critical temperature conditions. When the temperature exceeds predefined thresholds set above -4°C, the system triggers an audio signal to alert users immediately, as shown in *Figure 28* for the web dashboard and *Figure 29* for the mobile dashboard. This ensures a timely response to temperature variations, helping to maintain the quality and integrity of the frozen products.

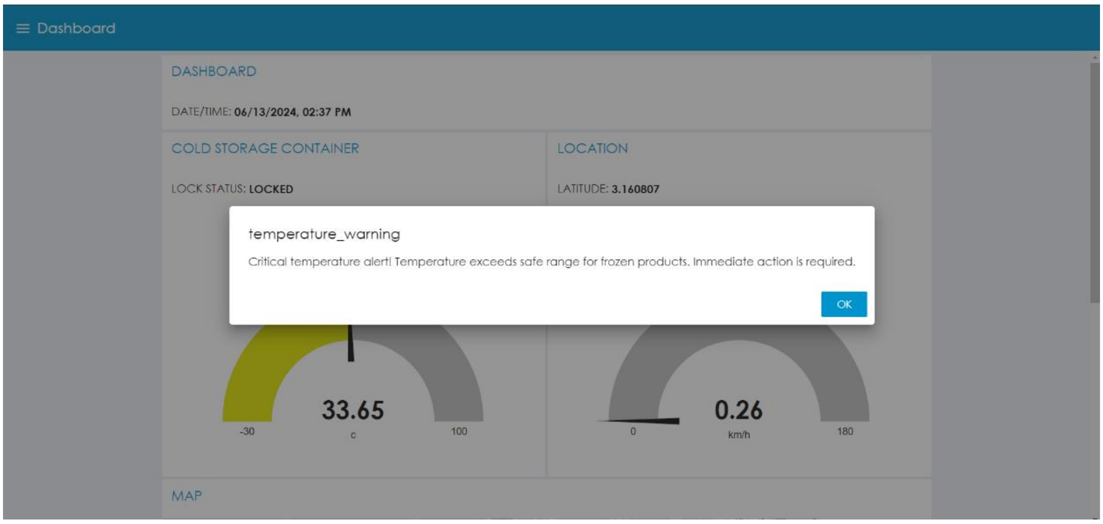


Figure 28: Web dashboard alert system

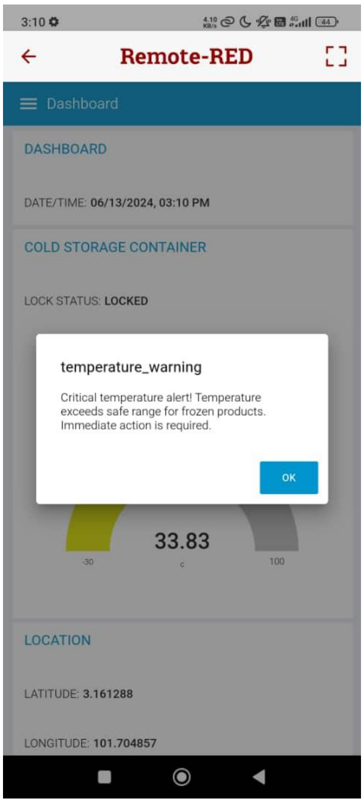


Figure 29: Mobile dashboard alert system

4.3.3.2 Access notification

Notifications of accessed worker IDs via RFID card are automatically generated and sent whenever there is a change in the lock state. Unauthorized attempts are also reported. This provides stakeholders with real-time updates on container security. Notifications appear at the top right corner of the web dashboard and the bottom of the mobile dashboard, as shown in *Figure 30* for the web dashboard and *Figure 31* for the mobile dashboard, *Figure 32* shows examples of access notifications.

Figure 30: Web dashboard access notification

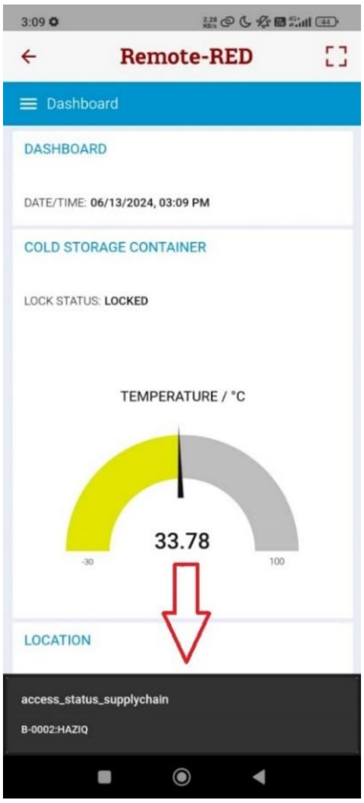


Figure 31: Mobile dashboard access notification

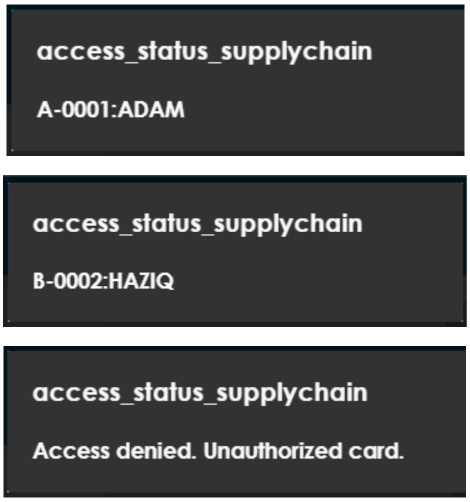


Figure 32: Examples of access notification

4.3.4 Location

The location feature tracks and displays the container's real-time location using GPS technology, providing essential information such as latitude, longitude, and speed in KM/H on the dashboard, as shown in *Figure 33*. Users can easily monitor the exact geographical position of the container at any given time, allowing for precise tracking throughout the supply chain journey. This functionality enhances logistics management by providing insights into the container's movement and ensuring timely deliveries.

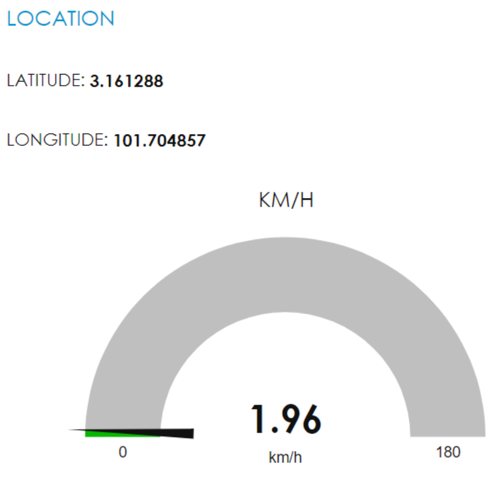


Figure 33: Dashboard of location

4.3.4.1 Map view

The map view feature enables zooming in and out for a more detailed view of street names and surrounding areas, benefiting not only logistics but also traffic management. As shown in *Figure 34,* It incorporates a car icon that indicates the transport location of the supply products, enhancing tracking and monitoring capabilities. With this feature, users can visualize the precise location of the container along its route.

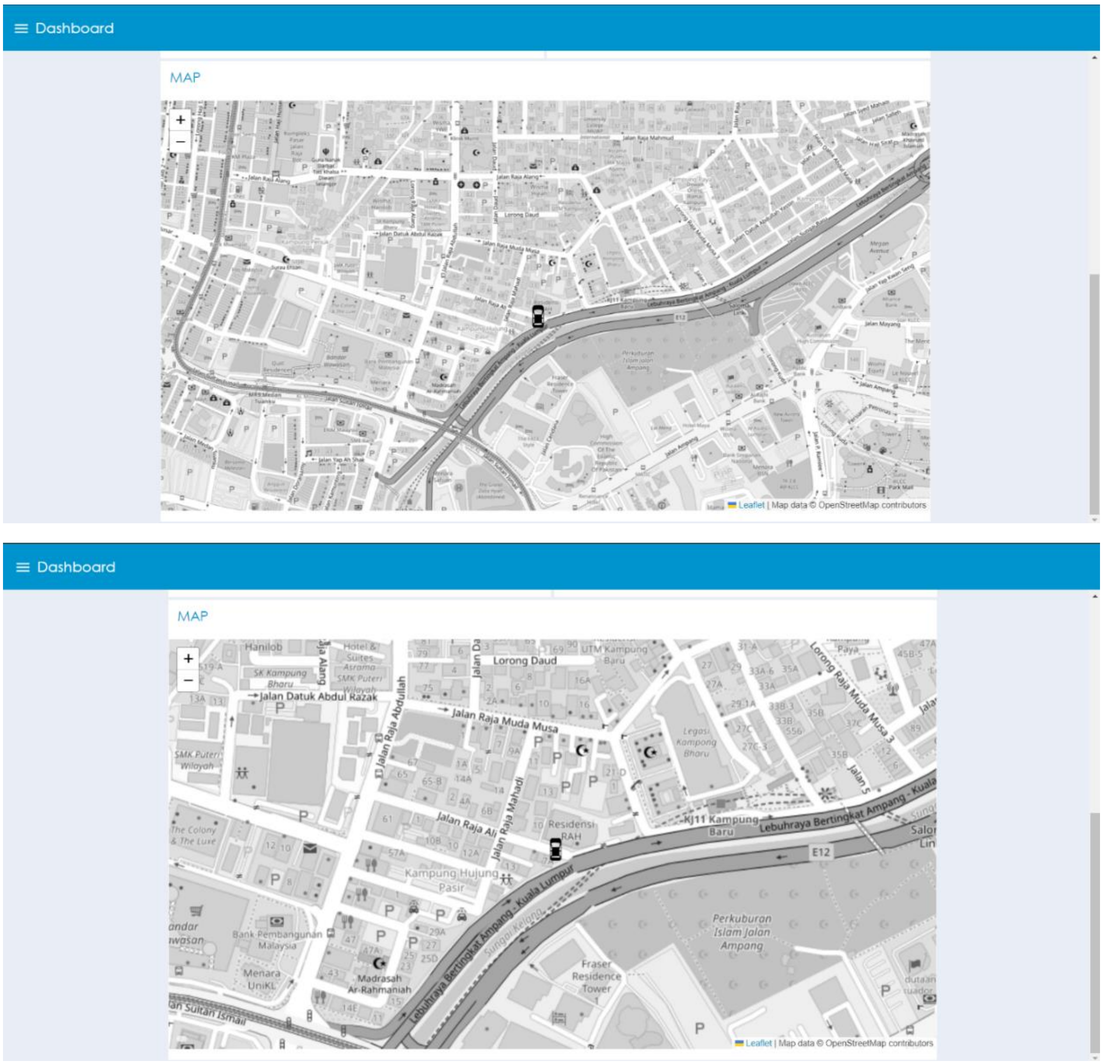


Figure 34: Map view of location

4.3.5 Invoice tracking

The invoice section plays a crucial role in managing transaction details within the system. Workers can access the invoice form conveniently by clicking the three-line icon located at the top left corner of the dashboard interface, as shown in *Figure 35*. It includes product information, supplier names, receiver names, and timestamps for each transaction record, ensuring comprehensive documentation, as shown in *Figure 36* for the web dashboard and *Figure 37* for the mobile dashboard. This allows stakeholders to easily track product movement, identify responsible suppliers and receivers, and maintain accurate transaction records for auditing and analysis purposes.

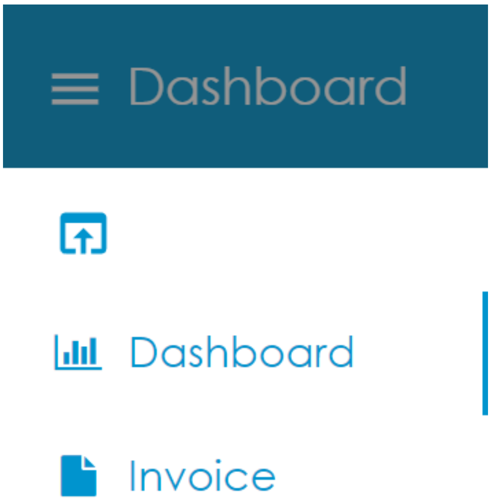


Figure 35: Accessing Invoice form

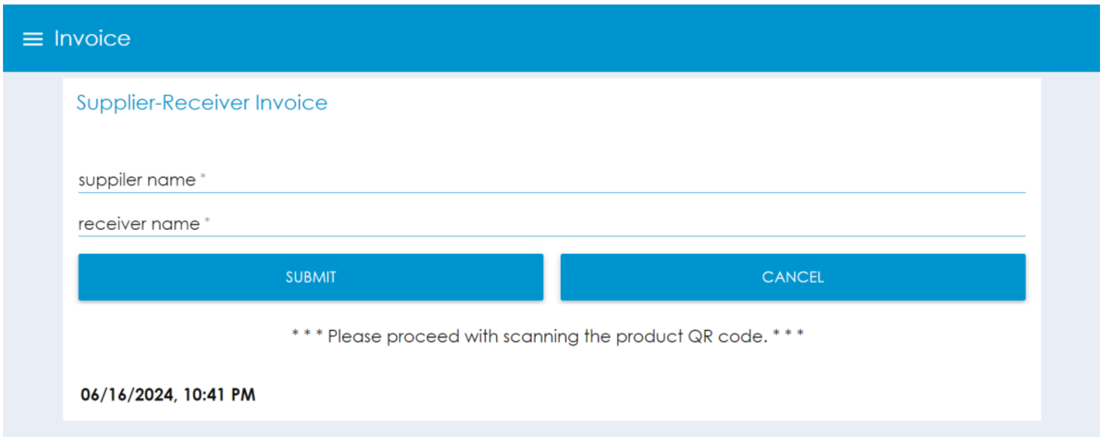


Figure 36: Web dashboard invoice form

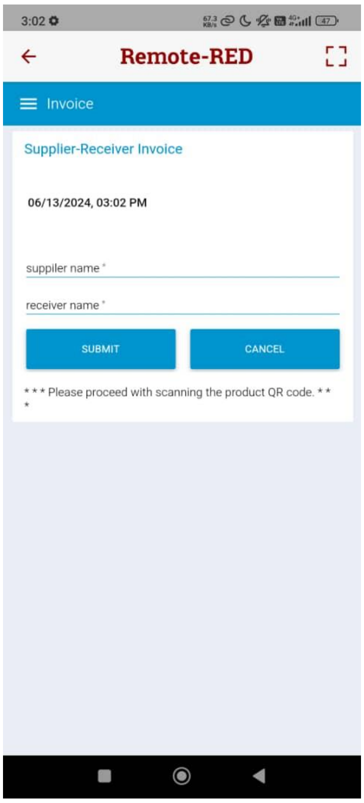


Figure 37: Mobile dashboard invoice form

4.3.5.1 Scanning product QR

To complete the invoice submission, product QR codes must be scanned with any device equipped with a QR scanner to update and verify inventory and invoice details, as shown in *Figure 38*. The confirmation output of invoice submission is displayed upon successfully scanning the product QR code, as shown in *Figure 39*. This feature streamlines inventory management and invoice processing, reducing manual errors and improving overall efficiency in supply chain operations.

Figure 38: QR scanning of product

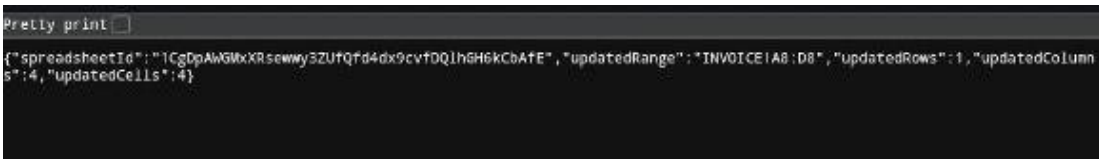


Figure 39: Successful scan and submission indicator for invoice

4.4 Database

The database system is fundamental in storing and managing the data generated by the IoT-Based Supply Chain of Frozen Food Monitoring system. It consists of two main databases, and all datasets are stored in cloud storage powered by Google. This cloud-based approach offers significant benefits, such as allowing stakeholders with authorized access to retrieve and interact with the database from anywhere. Additionally, cloud storage ensures data redundancy and reliability, reducing the risk of data loss due to hardware failures. It also provides automatic backups and updates, enhancing data security and integrity.

Data management is facilitated through Google Sheets, a powerful tool that simplifies data handling, sharing, and visualization. Google Sheets enables real-time collaboration, ensuring that stakeholders can work together efficiently and make informed decisions based on the most up-to-date information. The tool's integration with other Google services enhances its functionality, allowing for seamless data import and export, automated workflows, and customizable data views.

4.4.1 System database

The system database securely stores real-time data generated by the monitoring system, ensuring up-to-date information availability for stakeholders. The database is implemented using a CSV format managed through the Google Sheets platform. The primary data points injected into the database include:

- Timestamp:

  Captures the exact time when the data was recorded.
- Temperature (°C):

  Monitors the current temperature inside the container to ensure it remains within the required range for frozen products.
- Lock Status:

  Indicates whether the container is locked or unlocked.
- Access Status:

  Records the ID of the worker who accessed the lock, providing a traceable access log.
- GPS Data:

  Includes latitude, longitude, and speed (KM/H) to track the real-time location and movement of the container.

Data is injected into the database every minute, ensuring continuous monitoring. However, if a worker accesses the system via RFID and toggles the lock, this action interrupts the regular one-minute interval, causing the data to be injected immediately. This mechanism ensures that any critical changes in the system's state are captured and recorded in real time, providing an accurate and up-to-date record of the system's operational status. This comprehensive data collection and storage approach supports effective monitoring and management of the supply chain.

	A	B	C	D	E	F	G
1	DATE / TIME	TEMPERATURE	LOCK STATUS	ACCESS STATUS	LATITUDE	LONGITUDE	SPEED
2	29/05/24 22:45	29.42	LOCKED	B-0002:HAZIQ	3.161942	101.705230	3.43
3	29/05/24 22:45	29.44	UNLOCKED	B-0002:HAZIQ	3.161942	101.705230	3.43
4	29/05/24 22:46	29.48	UNLOCKED		3.160531	101.704471	4.46
5	29/05/24 22:47	29.49	UNLOCKED		3.160418	101.704624	1.19
6	29/05/24 22:48	29.5	UNLOCKED		3.161148	101.704847	0.94
7	29/05/24 22:49	29.49	UNLOCKED		3.160430	101.704729	1.83
8	29/05/24 22:50	29.5	LOCKED	A-0001:ADAM	3.160753	101.704873	5.69
9	29/05/24 22:51	29.48	LOCKED		3.161836	101.705125	2.37
10	29/05/24 22:52	29.49	LOCKED		3.161534	101.705015	1.7
11	29/05/24 22:53	29.51	LOCKED		3.161490	101.704992	1.26
12	29/05/24 22:54	29.51	LOCKED		3.161262	101.704893	0.13
13	29/05/24 22:55	29.53	LOCKED		3.161259	101.704873	2.65
14	29/05/24 22:56	29.53	LOCKED		3.161543	101.704955	1.54
15	29/05/24 22:57	29.53	LOCKED		3.161502	101.704953	1.3
16	29/05/24 22:58	29.55	LOCKED		3.161362	101.704856	0.85
17	29/05/24 22:59	29.57	LOCKED	Access denied. Unauthorized card.	3.161627	101.705020	2.31
18	29/05/24 23:00	29.55	LOCKED		3.161579	101.704990	0.41
19	13/06/24 14:54	33.41	LOCKED		3.160807	101.704716	0.26
20	13/06/24 15:55	34.4	LOCKED		3.161288	101.704857	1.96

Figure 40: System database

4.4.2 Invoice tracking database

The invoice tracking database manages transaction details, including product information, supplier names, receiver names, and timestamps. It is designed to ensure data integrity and completeness by requiring all necessary input submissions from the invoice form before data is injected into the database. Specifically, it mandates the inclusion of the supplier’s name, receiver’s name, and product ID obtained from the QR scan. This requirement ensures that comprehensive transaction records are maintained, facilitating effective auditing and traceability of products throughout the supply chain. By ensuring that all relevant details are captured, the invoice database supports accurate and reliable transaction management.

	A	B	C	D
1	DATE / TIME	SUPPLIER	RECEIVER	PRODUCT
2	28/05/24, 22:10	ADAM	HAZIQ	0001Sausage
3	29/05/24, 22:52	JOHN	CENA	0022ChickenNugget
4	30/05/24, 18:05	IQMAL	IRFAN	0001Sausage
5	01/06/24, 15:42	ZIQRI	AFIQ	1002Ikan
6	05/06/24, 14:46	AIMAN	AZMI	FT01-FishTofu
7	05/06/24, 14:56	AFIQ	ROSLAN	CC02-CrabChunk
8	15/06/24, 14:24	RAHIM	JOJO	FT02-FishTofu

Figure 41: Invoice tracking database

4.5 Data analysis

The data analysis and dashboard are conducted using Tableau to visualize and interpret the collected data effectively.

4.5.1 Real-time temperature (per minute)

Figure 42 shows the analysis monitoring and visualizing minute-by-minute temperature readings in a line chart to detect any abnormalities and ensure optimal storage conditions for frozen products.

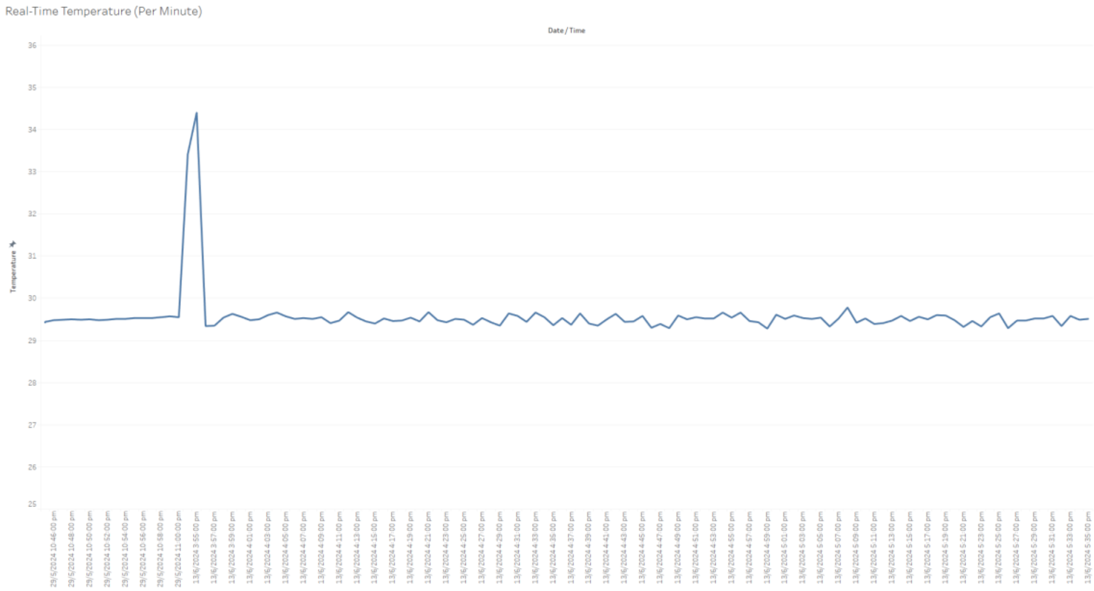
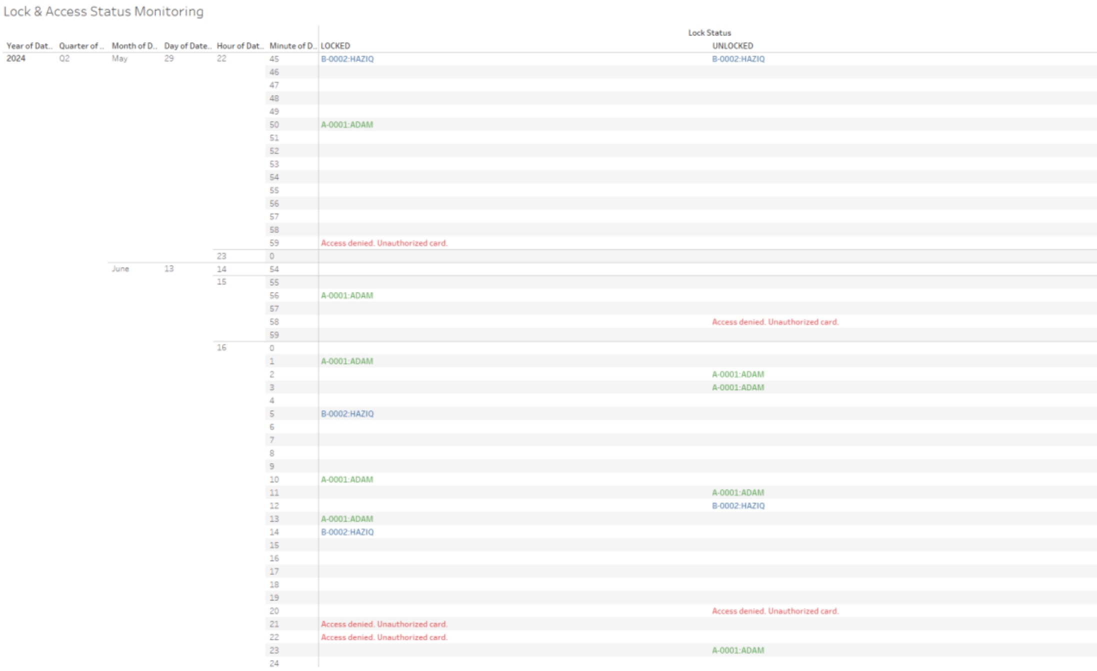


Figure 42: Real-time temperature (per minute)

4.5.2 Lock and access status analysis

Figure 43 analyses the tracking and display of the status of locks and access attempts, providing insights into security and access patterns.



Lock & Access Status Monitoring

Year of Dat..	Quarter of ..	Month of D..	Day of Date..	Hour of Dat..	Minute of D..	Lock Status LOCKED	UNLOCKED
2024	Q2	May	29	22	45	B-0002:HAZIQ	B-0002:HAZIQ
					46		
					47		
					48		
					49		
					50	A-0001:ADAM	
					51		
					52		
					53		
					54		
					55		
					56		
					57		
					58		
					59	Access denied. Unauthorized card.	
				23	0		
		June	13	14	54		
				15	55		
					56	A-0001:ADAM	
					57		
					58		Access denied. Unauthorized card.
					59		
				16	0		
					1	A-0001:ADAM	
					2		A-0001:ADAM
					3		A-0001:ADAM
					4		
					5	B-0002:HAZIQ	
					6		
					7		
					8		
					9		
					10	A-0001:ADAM	
					11		A-0001:ADAM
					12		B-0002:HAZIQ
					13	A-0001:ADAM	
					14	B-0002:HAZIQ	
					15		
					16		
					17		
					18		
					19		
					20		Access denied. Unauthorized card.
					21	Access denied. Unauthorized card.	
					22	Access denied. Unauthorized card.	
					23		A-0001:ADAM
					24		

Figure 43: Lock and access status analysis

4.5.3 Location and speed analysis

Figure 44 displays the analysis of real-time location data in map view, monitoring the movement and speed in specific locations of the transportation unit to identify patterns and potential issues in transportation efficiency.

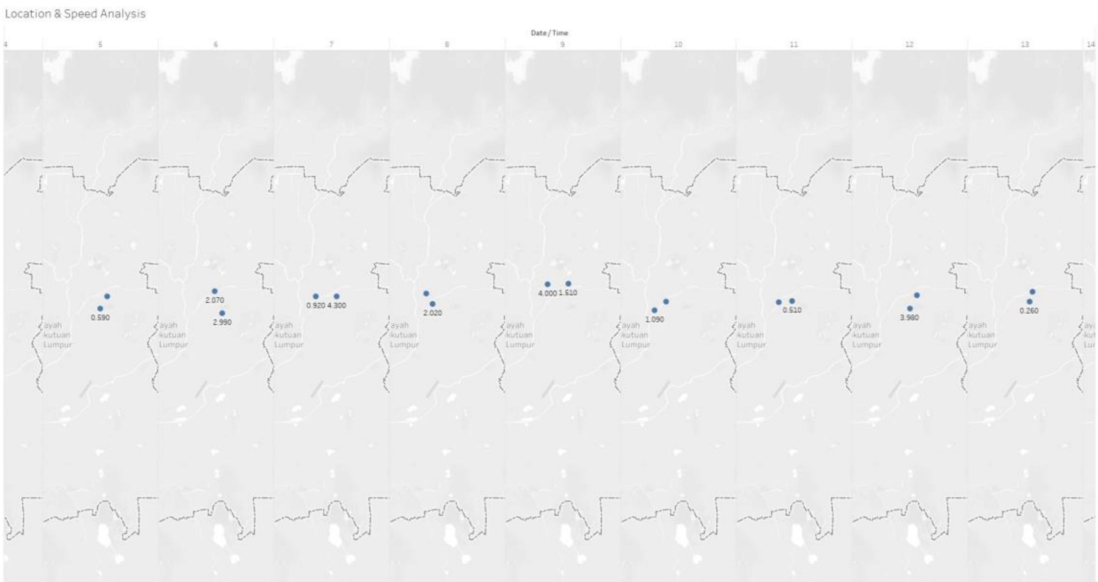


Figure 44: Location and speed analysis

4.6 Discussion of data analysis

Data analysis is critical in leveraging the collected information to enhance the frozen food supply chain's efficiency, reliability, and overall business performance. By examining the timestamp, temperature, lock status, access status, GPS data, and invoice data, valuable insights can be gained that drive informed decision-making and strategic improvements.

4.6.1 Timestamp analysis

The timestamp data provides precise logging of all recorded events and data points, allowing for detailed tracking of the system's operational timeline. This information is valuable for:

- Process Optimization:
  Analyzing timestamps helps identify patterns and bottlenecks in the supply chain, enabling more efficient scheduling and resource allocation.
- Incident Tracking:
  Timestamps allow for the exact timing of incidents, such as temperature breaches or unauthorized access, facilitating swift responses and corrective actions.
- Compliance Verification:
  Ensuring adherence to regulatory and contractual timelines for handling and transporting frozen goods.

4.6.2 Temperature data analysis

Temperature data is crucial for maintaining the quality and safety of frozen food products. Analyzing this data provides insights into:

- Quality Control:
  Monitoring temperature fluctuations helps ensure that products are stored and transported within the required temperature ranges, preserving their quality and safety.
- Predictive Maintenance:

Identifying trends in temperature data can indicate potential issues with refrigeration equipment, allowing for predictive maintenance and reducing the risk of spoilage.

- Regulatory Compliance:

  Demonstrating adherence to temperature control regulations helps avoid penalties and builds trust with consumers and regulatory agencies.

4.6.3 Lock status analysis

Lock status data provides visibility into the security of the container, offering benefits such as:

- Security Management:

  Tracking lock status ensures that containers remain secure during transit, reducing the risk of theft or tampering.

- Access Control:

  Analyzing lock status changes helps identify unauthorized access attempts, enabling the implementation of stronger security measures.

- Operational Efficiency:

  Ensuring that containers are promptly and securely locked and unlocked can streamline loading and unloading processes.

4.6.4 Access status analysis

Access status data records which personnel have accessed the system, providing valuable information for:

- Traceability:

  Maintaining a log of who accessed the system and when enhances accountability and traceability, important for both internal audits and regulatory compliance.

- Workforce Management:

  Analyzing access data can help optimize workforce deployment by understanding access patterns and workload distribution.

- Security Enhancement:

Identifying patterns in access data can highlight potential security vulnerabilities and inform improvements in access control protocols.

4.6.5 GPS data analysis

GPS data provides real-time location tracking of the transportation or container, offering several business advantages:

- Route Optimization:

  Analyzing GPS data helps identify the most efficient routes, reducing transportation time and fuel costs.
- Real-Time Tracking:

  Providing stakeholders with real-time location updates enhances transparency and enables proactive issue resolution, such as rerouting in case of delays.
- Delivery Verification:

  GPS data confirms delivery times and locations, helping resolve disputes and ensuring timely deliveries.

4.6.6 Invoice data analysis

Invoice data, including supplier names, receiver names, and product IDs, provides critical information for managing transactions and inventory. Analyzing this data offers several benefits:

- Transaction Verification:

  Detailed records of supplier and receiver names ensure that each transaction is properly documented and can be verified.
- Inventory Management:

  Tracking product IDs helps maintain accurate inventory records, preventing shortages or overstock situations.
- Audit and Compliance:

  Detailed transaction records support audits and compliance with financial regulations, ensuring transparency and accountability in supply chain operations.

4.6.7 Integrative insights

By combining and analyzing these diverse data sets, more valuable comprehensive insights can be gained:

- End-to-End Visibility:

  Integrating timestamp, temperature, GPS, and invoice data offers a complete view of the product's journey, ensuring all aspects of the supply chain are functioning optimally.
- Anomaly Detection:

  Correlating temperature breaches with lock and access data can help pinpoint the cause of issues, such as identifying if a temperature spike occurred due to the container being unlocked for an extended period.
- Performance Metrics:

  Aggregating data over time allows for the calculation of key performance indicators (KPIs), such as average delivery time, temperature compliance rates, and security breach incidents, which are crucial for continuous improvement efforts.

CHAPTER 5: CONCLUSION

5.1 Introduction

The development and analysis presented in this thesis demonstrate the successful implementation and potential of the IoT-Based Supply Chain of Frozen Food Monitoring system. Through the project, a prototype system was designed and evaluated, encompassing various components such as temperature monitoring, access control, location tracking, and transaction management. The system's dashboard provides real-time insights, enhancing visibility and control over the supply chain process. Achieving the project objectives confirms the system's capability to improve efficiency and quality assurance in the frozen food industry.

5.2 Summary of findings

The findings indicate that the system effectively monitors temperature, manages access control, tracks location, and handles transaction records. The integration of IoT technologies offers valuable real-time insights into supply chain operations.

5.3 Achievement of project objectives

The project successfully achieved its goals of developing a prototype system for monitoring frozen food supply chains in real time. The system provides features for temperature monitoring, access control, location tracking, and transaction management, aligning with the project objectives.

5.4 Key results and observation

Key results demonstrate the system's ability to improve supply chain visibility, ensure product quality, and optimize operational efficiency. Observations highlight the system's reliability and potential for enhancing overall supply chain management.

5.5 Implications and applications

The implications of this project extend to various industries, particularly those involving perishable goods transportation. The system's applications include improving inventory management, ensuring compliance with quality standards, and enhancing customer satisfaction.

5.6 Limitations and future work

Despite its successes, the system faces limitations such as dependency on stable connectivity and the need for periodic maintenance. Future work could focus on addressing these limitations, expanding the system's scalability, and integrating advanced analytics for predictive maintenance and optimization.

5.7 Conclusion

In conclusion, the IoT-Based Supply Chain of Frozen Food Monitoring system offers significant potential for revolutionizing supply chain management in the frozen food industry. By providing real-time monitoring, control, and insights, the system can enhance efficiency, quality, and customer satisfaction. Continued research and development in this area are essential for realizing the full benefits of IoT technology in supply chain management.

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APPENDIX A

TECHNICAL REPORT

IoT-BASED SUPPLY CHAIN OF FROZEN FOOD MONITORING

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***Abstract*—This thesis presents the development of a supply chain monitoring and management system using IoT technology to address challenges in supply chain logistics. The project aimed to implement a prototype capable of real-time monitoring and control of various parameters. The research methodology involved designing and implementing the system prototype to resemble a supply container or transportation truck with installed sensors controlled by a microcontroller. The main components include temperature sensors (AHT20), RFID reader for access control, GPS module for location tracking, and a web/mobile dashboard for remote monitoring. Additionally, a robust database system was developed to store sensor readings and transaction history, ensuring data integrity and facilitating seamless communication between components for real-time data transmission.**

Key findings indicate that the system effectively monitors temperature, manages access control through RFID authentication, tracks real-time location via GPS, and provides a user-friendly dashboard interface for data visualization. However, limitations such as dependency on stable WiFi connectivity and the need for periodic maintenance were identified.

The advantages of the system include enhanced supply chain visibility, improved temperature monitoring for perishable goods, and efficient access control. Despite the limitations, the system demonstrates promising potential for optimizing supply chain operations, particularly in the frozen food industry.

Keywords*—*IoT, Supply Chain Management, Frozen Food Logistics, Real-Time Monitoring, RFID, GPS.

1. INTRODUCTION

1.1 Introduction

The Internet of Things (IoT) has transformed numerous industries, and its potential in temperature-sensitive logistics is particularly significant. The IoT-Based Supply Chain of Frozen Food Monitoring project aims to address the challenge of maintaining the quality and safety of frozen products throughout the supply chain. With the increasing demand for frozen food, ensuring product integrity from production to consumption becomes crucial. This project introduces an innovative monitoring solution that leverages IoT technology to seamlessly track frozen food across the supply chain.

Moving beyond traditional tracking methods, the system provides real-time monitoring and optimization capabilities to ensure the integrity of frozen goods. By focusing on temperature-sensitive logistics, the project directly tackles critical challenges related to transporting and storing perishable products. The primary objective is to develop an efficient system that enhances operational efficiency and significantly reduces costs associated with spoilage and wastage due to inadequate monitoring.

Freezing is a common method used to preserve food, but challenges such as temperature fluctuations during storage can affect flavour, quality, and safety, as highlighted by Yahya et al. (2016). Temperature control throughout the supply chain is crucial to minimize the growth of harmful bacteria and the risk of foodborne illnesses. Different foods require precise temperature control, emphasizing the importance of maintaining temperatures during production, storage, transport, and sale.

De Vass et al. (2021) discuss the broad applicability of IoT in Supply Chain Management (SCM) but remark on challenges including lack of awareness, integration difficulties, and security concerns. Despite challenges, IoT creates opportunities such as real-time visibility of product movement. Real-world studies are needed to understand IoT's benefits fully. Addressing challenges like security and interoperability is crucial for successful implementation, as Industry 4.0 promotes IoT integration.

Nozari et al. (2021) emphasize the crucial role of big data analytics in enhancing decision-making in the FMCG industry supply chain, including frozen food logistics. Big data empowers customers, optimizes production, and ensures efficient delivery. Analyzing logistical data enhances decision-making power and allows diverse marketing strategies. Incorporating big data analytics is essential for optimizing performance and ensuring transparency.

Qian et al. (2022) outline the technical implementation of a cold chain monitoring system using LoRa for data transmission and blockchain for safety information. Gillespie et al. (2023) introduce an RTAD system for real-time monitoring, employing LTE-M communication and IoT architecture. Phase, A., & Mhetre, N. (2018) propose a sensory infrastructure for real-time monitoring using various sensors and cloud-based data processing.

This transition from challenges and solutions to data analytics highlights the importance of leveraging IoT-generated data for informed decision-making in frozen food logistics.

Overall, these studies provide insights into the challenges, solutions, and technical implementations in IoT-based supply chain management, laying the groundwork for our proposed project on IoT-Based Supply Chain of Frozen Food Monitoring.

1.2 Objectives

- To develop an IoT monitoring system for temperature, location tracking, and access status throughout the frozen food supply chain.
- To create a real-time dashboard designed for stakeholders, providing instant access to crucial data related to temperature, location tracking, and access status.
- To enhance product security by implementing measures within the IoT-based monitoring system to restrict access to authorized personnel.

1.3 Significance of Research

Research is crucial for understanding existing challenges in the frozen food supply chain and guiding solutions to enhance operational efficiency. It aids in integrating the latest IoT technologies, exploring innovative approaches, and ensuring compliance with industry regulations. Research also facilitates user-centric system design, identifies cost-effective technologies, and ensures long-term sustainability.

1.4 Project Scope

- Sensor Deployment:
  Installation of sensors at critical points in the frozen food supply chain to monitor temperature, location, and access status.
- Real-time Dashboard:
  Development of a dashboard for stakeholders to access vital insights for effective management.
- Data Management and Analysis:
  Establishment of a database for comprehensive data storage, analysis, and future insights.

This project aims to create an effective and sustainable IoT-based supply chain monitoring system for frozen food, contributing to enhanced product quality, safety, and efficiency throughout the supply chain.

2. METHODOLOGY

2.1 Introduction

This chapter explores the methodology applied in the IoT-Based Supply Chain of Frozen Food Monitoring project, outlining the systematic approach used to address research questions and achieve project objectives. It provides a concise overview of the research design, data collection methods, and analytical techniques utilized in the investigation, introducing the framework for a detailed exploration in the following sections.

2.2 Project architecture

This section outlines the overall structure of the project, detailing the various flowcharts and diagrams used to design and implement the system.

2.2.1 Project flowchart

The project flowchart provides a sequential representation of the key stages and milestones in the development of the IoT-Based Supply Chain of Frozen Food Monitoring system.

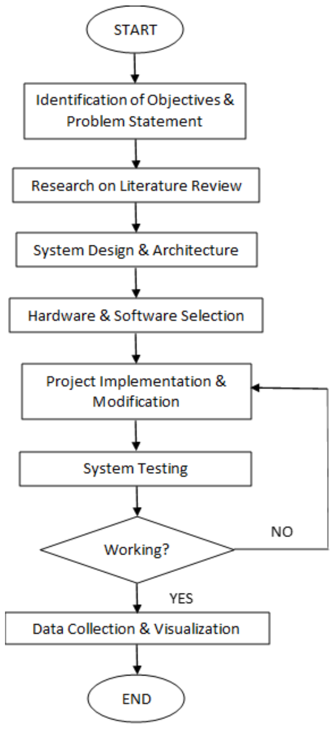

Figure 1: Project flowchart

•Identification of Objectives & Problem Statement:
Objectives and the problem statement are identified and outlined. This phase is essential for setting the project's direction and understanding the challenges that need to be addressed.

•Research on Literature Review:
A comprehensive literature review is conducted to understand existing solutions, challenges, and best practices in the field of IoT applications in supply chain management, particularly within the frozen food domain.

•System Design & Architecture:
The system is designed, and its architecture is outlined. This involves planning the integration of components such as sensors, microcontrollers, and databases, aligning with the project's objectives.

•Hardware & Software Selection:
Based on the system design, the appropriate hardware components and software tools are selected. This step is critical for ensuring compatibility and optimal performance.

•Project Implementation & Modification:
The actual implementation of the project takes place, where the selected hardware and software are integrated. As the implementation progresses, modifications may be made to enhance system efficiency or address unforeseen challenges.

•System Testing:
Comprehensive testing is conducted to validate the functionality of the IoT-based system. Troubleshooting is performed to identify and rectify any issues that arise during the testing phase.

•Data Collection & Analysis:
With the system in operation, data collection begins. The collected data is then visualized through dashboards, providing stakeholders with real-time insights into the frozen food supply chain.

2.2.2 Block diagram

The block diagram illustrates the key components of the IoT-Based Supply Chain of Frozen Food Monitoring system and their interconnections.

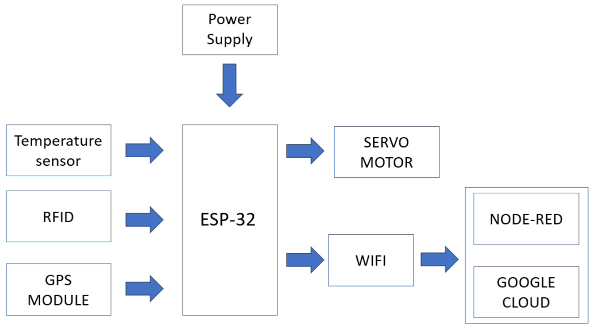

Figure 2: Block diagram

•Temperature Sensor:
This component plays a vital role in monitoring the temperature of frozen food throughout the supply chain. It provides real-time data on the environmental conditions to ensure that the prescribed temperature levels are maintained, thus safeguarding the quality and safety of frozen products.

•RFID (Radio-Frequency Identification):
The RFID module serves as a security measure to control access to the package. Only authorized suppliers with the corresponding RFID credentials can access and open the package, enhancing the security of frozen products during transportation and storage.

•GPS Module:
Location tracking is integrated through the GPS module, ensuring that the real-time location of the shipment is known. This feature aids in logistics management, allowing stakeholders to track the movement of frozen products throughout the supply chain.

•Servo Motor:
Acting as a lock/unlock mechanism triggered by the RFID module, the servo motor enhances the security of the package. It ensures that access is granted only to authorized personnel, preventing unauthorized handling of frozen food items.

•ESP32 Microcontroller:
This central processing unit controls the overall system. It is equipped with Wi-Fi capabilities, enabling real-time data transmission and remote monitoring. The ESP32 receives power from the power supply unit and manages communication between the sensors, GPS module, and RFID reader.

•Power Supply:
This unit provides the necessary electrical power to all components of the system, ensuring stable operation.

•Wi-Fi:
Enabled by the ESP32, the Wi-Fi connection facilitates real-time data updates and remote access to the dashboard, ensuring seamless communication with the server.

•Node-RED:
Serving as the dashboard interface, Node-RED provides a user-friendly platform for both end-users and suppliers. It visualizes the real-time data collected from the temperature sensor and GPS module, offering a comprehensive overview of the frozen food supply chain.

•Google Cloud:
Google Cloud services are employed for efficient and secure storage of the collected data. Google Cloud ensures robust infrastructure for data processing and storage. Essential data such as temperature records, RFID authorizations, GPS coordinates and invoice tracking are stored, facilitating data

retrieval and analysis for monitoring the entire lifecycle of frozen food products.

2.2.3 System flowchart

The system flowchart illustrates the operational sequence of the IoT-Based Supply Chain of Frozen Food Monitoring system.

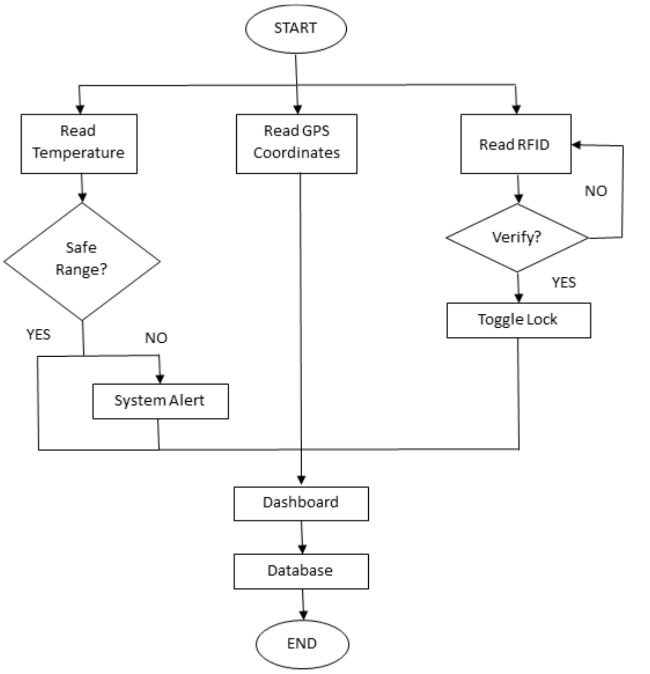

Figure 3: System flowchart

•Temperature Reading:
The system reads the temperature of the loaded products. If the temperature is within the specified range, the data is logged into the database. If the temperature falls outside the acceptable range, a system alert is generated and recorded in the database.

•GPS Reading:
The system reads the GPS coordinates to track the real-time location of the products. The GPS data is then stored in the database for further analysis.

•RFID Verification:
The RFID module reads the RFID credentials. Once verified, the system checks the status. If the status indicates that the package is locked, the system proceeds to unlock it using the servo motor. If the status indicates that the package is already unlocked, the system locks it.

•Dashboard:
The recorded data is processed and visualized on the dashboard via Node-RED. This provides stakeholders with real-time insights into temperature conditions, location, and access status throughout the frozen food supply chain.

•Database Update:
All relevant data, including temperature readings, GPS coordinates, RFID verification status, and servo motor actions, is updated in the database for future reference and analysis.

2.2.4 Invoice tracking

The invoice tracking flowchart outlines the process of creating and managing invoices, ensuring every transaction is properly documented. This process enhances traceability, reliability, and efficiency within the supply chain.

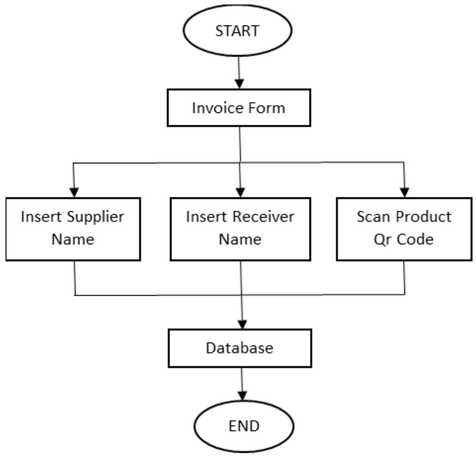

Figure 4: Invoice tracking flowchart

•Invoice Form:
The invoice form is accessible via a digital dashboard, to fill with transaction details.

•Insert Supplier Name:
To record responsible personnel in supplying frozen products.

•Insert Receiver Name:
To record responsible personnel in receiving frozen products.

•Scan Product QR Code:
The QR code on the product is scanned using any device with a QR scanner. To record specific supplying products by unique ID for traceability.

•Database:
The invoice information is updated in the database with a timestamp for future reference and analysis.

2.2.5 Data storage

The data storage flowchart illustrates the process of managing data. This process enables stakeholders to access real-time insights and historical data, enhancing decision-making and system reliability.

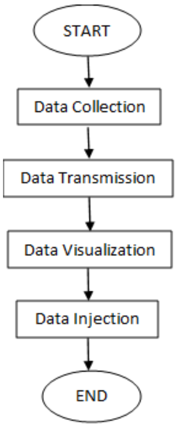

Figure 5: Data storage flowchart

•Data Collection:
Data collected from sensors, including temperature readings, GPS coordinates, and access control statuses, is processed by the ESP32 microcontroller.

•Data Transmission:
Processed data is then transmitted to Node-RED via MQTT protocol for further processing and visualization.

•Data Visualization:
Node-RED processes and visualizes the data on custom dashboards, providing real-time insights to stakeholders.

•Data Injection:
Processed data is injected into Google Cloud and Google Sheets for long-term storage and analysis.

2.3 Parameter measured

In the context of the IoT-Based Supply Chain of Frozen Food Monitoring, ensuring the quality, security, and traceability of frozen food products relies on measuring critical parameters, namely temperature, location, and access status. The thoughtful selection of hardware components, including temperature sensors, GPS modules, and RFID systems, is important in achieving project objectives. This section provides a detailed examination of the technical decisions made for measuring and monitoring these crucial parameters, establishing the foundation for subsequent implementation and testing phases.

2.3.1 Temperature measurement system

Maintaining an optimal temperature range is crucial for preserving the quality and safety of frozen food products throughout the supply chain. The recommended temperature range for storing and transporting frozen food is typically set between -18°C (0°F) and -23°C (-10°F). Adhering to this temperature range ensures that frozen products remain in a frozen state, preventing the growth of harmful microorganisms and maintaining the desired texture, flavour, and nutritional value.

If the temperature reading deviates beyond the specified range, triggering a condition where it exceeds -18°C, an immediate system alert is generated. This alert serves as a critical notification to stakeholders, indicating a potential compromise in the preservation of frozen products. The system captures and logs this alert in the database, allowing for prompt corrective actions to be taken, such as adjusting the temperature settings or addressing any issues that may impact the temperature control system.

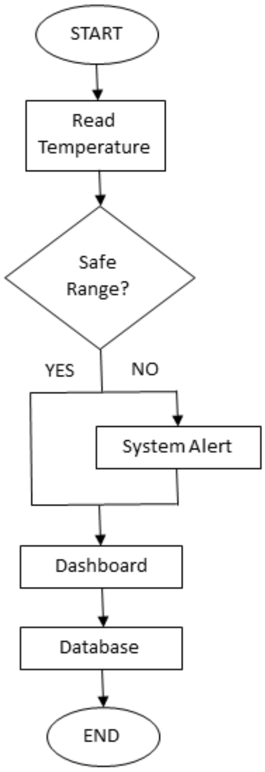

Figure 6: Flowchart of temperature measurement system

2.3.1 Temperature sensor module

The AHT20 temperature sensor has been selected for its precision and reliability in measuring temperature. The AHT20 is a high-precision digital temperature sensor specifically designed for applications requiring accurate temperature measurements, making it suitable for monitoring frozen food conditions within the supply chain. The sensor is compact, lightweight, and integrates seamlessly into the IoT system. (Guangzhou Aosong Electronic Co., 2020)

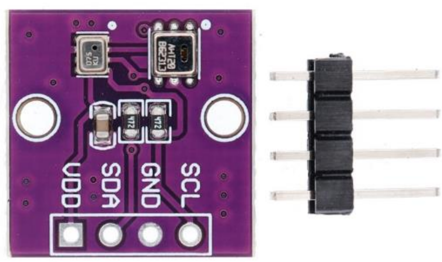

Figure 7: AHT20 temperature sensor

The AHT20 sensor employs a thermocouple-based temperature sensing mechanism. It utilizes a thin-film capacitor to measure changes in capacitance, which are directly proportional to variations in temperature. This capacitive measurement method ensures high accuracy and responsiveness, making the AHT20 an ideal choice for applications where precise temperature monitoring is critical (Guangzhou Aosong Electronic Co., 2020). The digital output from the sensor is interfaced with the ESP32 microcontroller in the system architecture. This integration allows real-time temperature data to be collected and further processed for analysis and visualization.

Supply voltage	2.2 - 5.5V
Measuring range	-40 ~ + 85 ℃
Temperature accuracy	± 0.3 ℃
Resolution	0.01℃
Response time	5s
Output signal	I^2C signal
Weight	4 g
Dimensions	10x20 mm

Table 1: AHT20 specification

2.2.2 Real-time location tracking system

Real-time location tracking is a fundamental and crucial aspect of the IoT-Based Supply Chain of Frozen Food Monitoring system for several key reasons:

•Enhanced Logistics Management:

Real-time location tracking allows for continuous monitoring and visibility of the exact whereabouts of frozen food shipments throughout the supply chain. This enhanced logistics management ensures efficient route planning, timely deliveries, and proactive response to any unexpected events or delays.

•Optimized Supply Chain Operations:

The ability to track the real-time location of frozen food products enables supply chain professionals to optimize operations. This includes identifying potential bottlenecks, streamlining transportation routes, and making data-driven decisions to enhance overall supply chain efficiency.

•Security and Risk Mitigation:

Tracking the location of frozen food products in real-time adds a layer of security to the supply chain. In the event of any anomalies or deviations from the planned route, immediate alerts can be generated, enabling rapid response to potential security threats or risks, such as theft or tampering.

•Accountability and Transparency:

Real-time location data fosters accountability and transparency among all stakeholders in the supply chain. It provides verifiable evidence of the movement and handling of frozen food products, promoting trust and reliability among suppliers, distributors, and end-users.

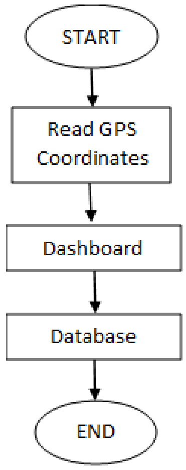

Figure 8: Location tracking system flowchart

2.2.2.1 GPS module

The NEO-6M GPS module has been selected as a key component in the IoT-Based Supply Chain of Frozen Food Monitoring system for its reliable and accurate real-time location tracking capabilities. The NEO-6M is a compact and cost-effective GPS module designed for applications requiring precise location data.

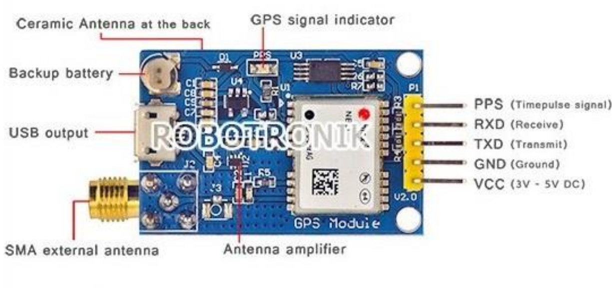

Figure 9: NEO-6M GPS

The NEO-6M GPS module operates based on the Global Navigation Satellite System (GNSS), utilizing signals from multiple satellites to determine the device's precise location. The working principle involves:

•Satellite Reception:

The module receives signals from satellites orbiting the Earth. The NEO-6M is capable of connecting to both GPS and GNSS satellites, enhancing its accuracy and reliability. (Das D, 2022)

•Trilateration:

The module calculates its position by trilateration of the signals received from at least three satellites. Trilateration involves determining the intersection point of spheres created by the distance measurements from each satellite. (LastMinuteEngineers, n.d.)

•Data Processing:
The GPS module processes the received signals and computes the latitude, longitude, altitude, and time information. This data is then transmitted to the microcontroller for further processing and integration into the overall system. (Das D, 2022)

Supply voltage	3.3V - 5V DC
Operating current	45mA
Baud rates	9600 (configurable from 4800 to 115200)
Navigation update rate	5Hz maximum (1HZ default)
Capture time	Cool start: 27s (fastest) Hot start: 1s
Operating temperature range	-40 to +85°C
Separated	18 X 18mm GPS antenna
Dimension	22 X 30 X 13mm
Weight	19g

Table 2: NEO-6m GPS module specifications

2.3.3 Access status monitoring system

The Access Status Monitoring System employs RFID technology to enhance security by controlling access to the packages. Only authorized suppliers possessing the corresponding RFID credentials are granted access to open the package. The system utilizes a servo motor as a lock/unlock mechanism, responding to signals from the RFID module.

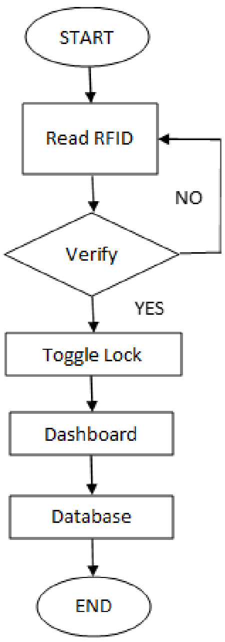

Figure 10: Access status monitoring system flowchart

The RFID module reads the RFID credentials provided by suppliers attempting to access the package. Once RFID verification is successful, the system checks the status of the package. If the status indicates that the package is locked, the system proceeds to unlock it using the servo motor. Conversely, if the status reveals that the package is already unlocked, the system initiates the locking mechanism. This mechanism is a crucial layer of security in controlling package access. Every access attempt, successful verifications, and any changes in the lock/unlock status are monitored, and the corresponding data is stored in the database to ensure a detailed audit trail.

2.3.3.1 RFID module

The RC522 is a popular RFID reader and writer module that provides a cost-effective solution for RFID-based access control. Widely used in various applications, it is specifically chosen for its reliability, ease of integration, and compatibility with microcontrollers.

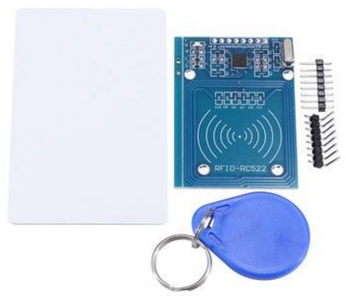

Figure 11: RFID RC522

The RC522 RFID module operates based on Radio-Frequency Identification (RFID) technology. As explained by LastMinuteEngineers (n.d.), the working principle involves:

•RFID Tags and Cards:
Authorized suppliers are provided with RFID tags or cards containing unique identification information. These tags or cards are associated with the supplier's credentials.

•Reader and Antenna:
The RC522 module consists of a reader and an antenna. When a tagged item or card is brought into proximity with the antenna, it energizes the RFID tag, allowing it to transmit its unique identifier.

•Data Transmission:
The module reads the transmitted data from the RFID tag and sends it to the connected microcontroller, in this case, the ESP32, for further processing.

•Verification and Access Control:
The microcontroller verifies the received RFID data against the authorized credentials stored in the system. If the verification is successful, access is granted.

Working current	13—26mA/ DC 3.3V
Working frequency	13.56MHz
Card reading distance	0～60mm（mifare1 card）
Protocol	SPI
Data communication speed	Maximum 10Mbit/s
Card types supported	Mifare1 S50, Mifare1 S70, Mifare UltraLight, Mifare Pro, Mifare Desfire
Dimension	40mm×60mm
Max SPI speed	10Mbit/s

Table 3: RFID RC522 specifications

2.3.3.2 Servo motor module

The Tower Pro 9g SG90 servo motor is a critical component in the Access Status Monitoring System of the IoT-Based Supply Chain of Frozen Food Monitoring. The Tower Pro 9g SG90 is a widely used micro servo motor known for its compact size, lightweight design, affordability and versatility (Sawkare R, 2020).

Figure 12: Tower Pro 9g SG90 servo motor

The servo motor receives a control signal from the microcontroller, which determines the desired position or angle of rotation. It consists of a DC motor, a set of gears, and a feedback potentiometer. The DC motor, installed with the bolt lock of the container/transportation, acts as a safety mechanism. Gears amplify the rotational movement of the DC motor to achieve precise control, while the potentiometer continuously provides feedback on the motor shaft's current position (Sawkare R, 2020). This feedback loop ensures that the motor adjusts its position until the desired angle is reached. The output shaft of the servo motor rotates to the specified angle based on the control signal received, enabling the locking or unlocking of the package.

Operating Voltage	4.8 V (~5V)
Operating speed	0.1 s/60 degree (Total 180 degree)
Weight	9 g
Dimension	22.2 x 11.8 x 31 mm approx.
Stall torque	1.8 kgf·cm
Dead band width	10 µs

Table 4: Tower Pro 9g SG90 servo motor specifications

2.4 Microcontroller

The ESP-WROOM-32 microcontroller is a crucial element in the architecture of the IoT-Based Supply Chain of Frozen Food Monitoring system. As the central processing unit, it coordinates the functions of various modules, sensors, and actuators within the system. It belongs to the ESP32 series and is selected for its dual-core processing capabilities, low power consumption, and built-in Wi-Fi and Bluetooth connectivity (Elprocus, 2019).

Figure 13: ESP-WROOM-32

The microcontroller features two processing cores, allowing for parallel execution of tasks and improved overall system performance. Integrated Wi-Fi and Bluetooth capabilities enable seamless communication with other devices and networks. The ESP-WROOM-32 is designed for energy efficiency, making it suitable for battery-powered applications. It comes equipped with a variety of peripherals, including GPIO pins, I2C, SPI, UART, analog-to-digital converters, and more, providing flexibility for interfacing with sensors and actuators (Elprocus, 2019).

Bandwidth	72 MHz
Data Rate	150 Mbps
Interface	Ethernet, I2C, I2S, SPI, UART
Max Frequency	2.484 GHz
Max Operating Temperature	85 °C
Max Supply Voltage	3.6 V
Min Operating Temperature	-40 °C
Min Supply Voltage	3 V
Nominal Supply Current	500 mA
Number of ADC Channels	16
Number of GPIO	32

Table 5: ESP-WROOM-32 specifications

2.5 Programming software

The programming software component of the IoT-Based Supply Chain of Frozen Food Monitoring system is a critical element that enables the seamless integration and operation of hardware components, data processing, and communication.

2.5.1 Arduino IDE

Arduino IDE (Integrated Development Environment) is a vital software component in the IoT-Based Supply Chain of Frozen Food Monitoring system, serving as the programming platform for the ESP-WROOM-32 microcontroller. Arduino IDE is an open-source software application that provides a user-friendly environment for writing, compiling, and uploading code to Arduino-compatible microcontrollers.

Figure 14: Arduino IDE

The IDE features a text editor for writing and editing code. It supports various programming languages, primarily focusing on the Arduino programming language based on C/C++. Arduino IDE includes a built-in compiler that translates the written code into machine-readable instructions for the microcontroller. It provides a straightforward mechanism for uploading compiled code to the ESP-WROOM-32 microcontroller, enabling rapid prototyping and testing. The IDE allows easy integration of external libraries, providing pre-written code for common functions and peripherals, streamlining the development process. A crucial tool for debugging, the serial monitor allows real-time communication between the microcontroller and the computer, displaying output messages and aiding in code troubleshooting (Aqeel A, 2018).

2.5.2 Node-RED

Node-RED is a fundamental software component in the IoT-Based Supply Chain of Frozen Food Monitoring system, serving as a visual programming tool for creating the system's dashboard and facilitating data flow between devices and databases. Node-RED is an open-source flow-based development tool for the visual programming of event-driven applications. It provides a browser-based interface that allows users to wire together devices, APIs, and online services (Lundberg M, 2024). In this project, Node-RED is employed to create a user-friendly dashboard, subscribe to the MQTT connection from the broker, inject data into the cloud database and manage functions of project flows.

Figure 15: Node-RED

Node-RED utilizes a flow-based programming paradigm, nodes are connected to define the flow of data and actions. The platform includes a rich library of pre-built nodes that represent different functions, services, and protocols. Users can easily drag and drop nodes onto the canvas to construct their application. Node-RED supports integration with a wide range of devices, APIs, and protocols, making it suitable for IoT applications. It enables the creation of interactive dashboards with customizable UI elements, providing a real-time view of system data. The visual interface makes it accessible to users with varying levels of programming expertise, allowing for quick and efficient development (Lundberg M, 2024)..

2.6 Database management

Effective data management is essential for the IoT-Based Supply Chain of Frozen Food Monitoring system, allowing stakeholders to gain valuable insights from real-time and historical data. This section discusses the strategies for data visualization and storage implemented in the system.

2.6.1 Node-RED dashboard

Node-RED serves as the central dashboard interface, providing both web and mobile options for real-time data visualization. Utilizing a variety of nodes and functions, the dashboard is -designed to display crucial information such as temperature readings, GPS coordinates, lock status, and other relevant data points. Stakeholders can easily monitor the status of the frozen food supply chain through this intuitive dashboard interface. The web dashboard offers a comprehensive view accessible via browsers, while the mobile dashboard provides on-the-go access for users, ensuring flexibility and convenience.

2.6.2 Google Cloud

Google Cloud services, a cloud computing platform by Google, are leveraged for robust data storage and processing capabilities. With Google Cloud, the system can efficiently handle large volumes of data generated by the monitoring system. It provides a secure and reliable infrastructure that ensures data integrity throughout transmission and storage processes. Storing data in the cloud offers benefits such as scalability, allowing the system to adapt to changing data storage needs easily. Additionally, cloud storage provides redundancy and disaster recovery options, ensuring data availability and reliability. Integration with other Google services enables seamless data management and analysis, enhancing the overall efficiency of the system (Mixon & Wigmore, 2023).

Figure 16: Google Cloud

2.6.3 Google Sheets

In addition to Google Cloud, Google Sheets is utilized as a supplementary tool for data management and visualization. Google Sheets offers a familiar and user-friendly interface for stakeholders to view, analyze, and share data stored in the cloud. Stakeholders can easily collaborate and access critical information, facilitating better decision-making processes. Google Sheets enhances the accessibility of data, allowing stakeholders to interact with the information effortlessly and supporting seamless data sharing and reporting within the organization.

Figure 17: Google Sheets

2.7 Circuit diagram

The circuit diagram illustrates the integration of components in the system. The AHT20 sensor interfaces with the ESP-WROOM-32 microcontroller via its serial clock (SCL) and serial data (SDA) pins, connected to GPIO pins 22 and 21 respectively, operating at 3.3V. The RFID module connects to the microcontroller with 3.3V power, utilizing pins for reset, data input/output (MISO/MOSI), serial clock (SCK), and serial data (SDA). A 5V-powered servo motor receives control signals through pin 13. The NEO-6M GPS module communicates with the microcontroller via 5V power, using serial communication with RX (receive) on pin 17 and TX (transmit) on pin 16. This diagram provides a comprehensive overview of the hardware architecture, emphasizing connectivity and power considerations across the system.

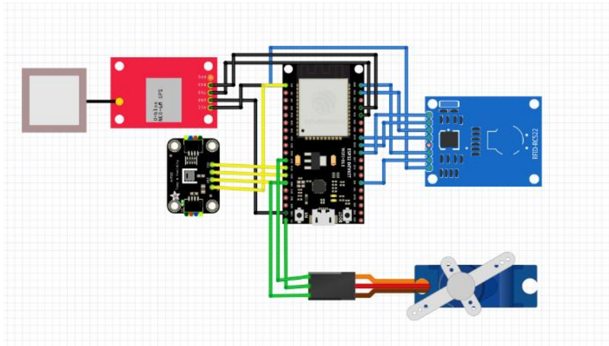

Figure 18: Circuit diagram

3. RESULT AND DISCUSSION

3.1 Introduction

This chapter presents the outcomes of the project and provides an in-depth examination of the various components developed. It begins with an overview of the system programs, followed by a detailed analysis of the project prototype, highlighting the installation of sensors and microcontrollers. The features of the dashboard are then explored, covering both the web and mobile interfaces, temperature monitoring with alert systems, lock state notifications, and location tracking capabilities. Additionally, the invoice management system is discussed, with a focus on product QR scanning. The chapter concludes with an analysis of the system database configurations, detailing their structures and roles within the project.

3.2 System programs

The system programs detail the operational workflow of the IoT-Based Supply Chain of Frozen Food Monitoring. It provides a comprehensive analysis of the stages and decision points involved in the system's operation, programmed using the Arduino IDE and written in C++.

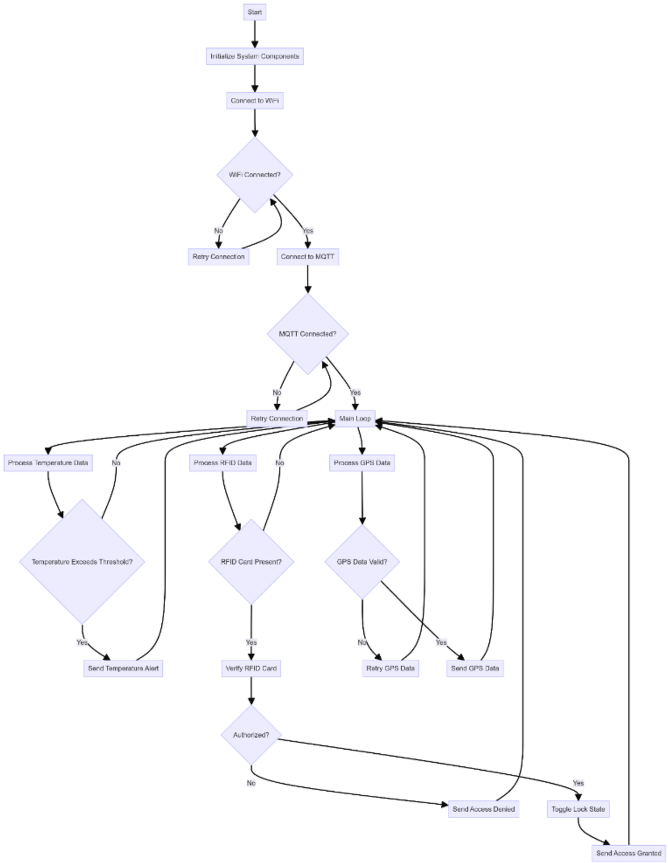

Figure 19: System programs flowchart

The system initialization begins by setting up all necessary components and attempting to establish a Wi-Fi connection for data transmission. This phase involves initializing hardware and software components, such as sensors and communication modules. Once initialized, the system tries to connect to a Wi-Fi network. If successful, it proceeds to connect to the MQTT broker, which is essential for messaging between devices and the central server. In case of a failed Wi-Fi connection, the system retries until a connection is established, ensuring continuous operation.

Following a successful Wi-Fi connection, the system attempts to establish communication with the MQTT broker. MQTT (Message Queuing Telemetry Transport) is used for efficient messaging between devices and the central server. This step involves establishing a connection with the MQTT broker, which acts as a communication intermediary. If the MQTT connection is successful, the system proceeds to the main operational loop. However, if the connection fails, the system retries the connection process to ensure reliable communication.

The main operational loop constitutes the core functionalities of the monitoring system. It involves processing temperature, RFID, and GPS data to ensure effective monitoring of the supply chain. Each iteration of the loop includes specific checks and actions. Temperature data is monitored to detect threshold exceedances and trigger alerts if necessary. RFID data is processed to verify access authorization and toggle the lock state accordingly. GPS data is checked for validity and sent to the central system for tracking. These processes ensure continuous monitoring and control of critical parameters throughout the supply chain journey.

3.2 Project prototype

The project prototype consists of an icebox modified to resemble a supply container or transportation, making it suitable for supply chain simulation. Sensors and a microcontroller are installed within the prototype to achieve the project objectives.

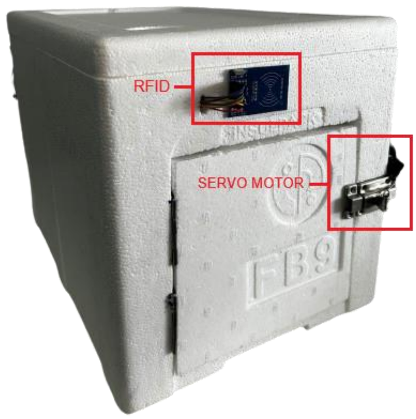

Figure 20: Prototype front view

The RFID reader is installed above the door for access control. A servo motor and door lock mechanism are installed on the side of the icebox, allowing the door to lock and unlock based on RFID access, as shown in Figure 20.

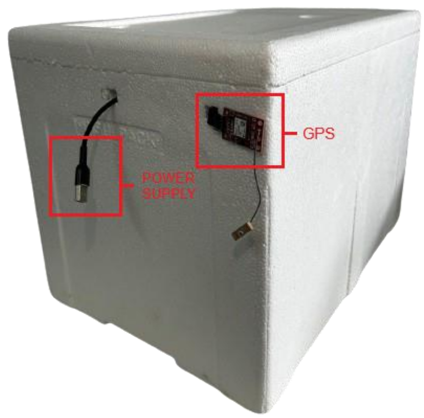

Figure 21: Prototype back view

The GPS module is installed at the back of the box for location tracking, and the power supply unit, which powers the entire system, is also located there, as shown in Figure 21.

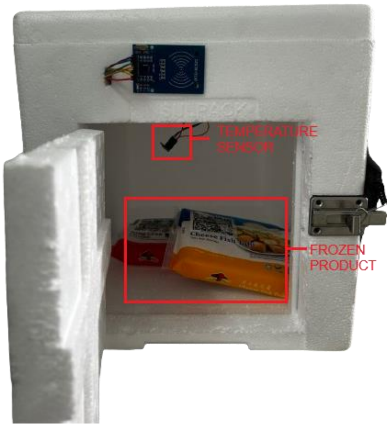

Figure 22: Prototype inside view

The AHT20 temperature sensor is installed inside the icebox to monitor temperature. Frozen products with unique ID QR codes for tracking purposes are loaded inside, as shown in Figure 22.

3.2.1 Registered RFID for authorized personnel

The system registers RFID cards of authorized personnel, ensuring access control within the supply chain. Each RFID card is uniquely identified and corresponds to specific personnel, such as ID cards A-0001:ADAM, where the unique ID is associated with the worker's name, as shown in Figure 23. When authorized personnel present their RFID card, the system verifies the ID against the registered database. If the ID matches an authorized user, access is granted, allowing them to interact with the system. Conversely, unrecognized RFID cards are denied access, enhancing security and control over system operations.

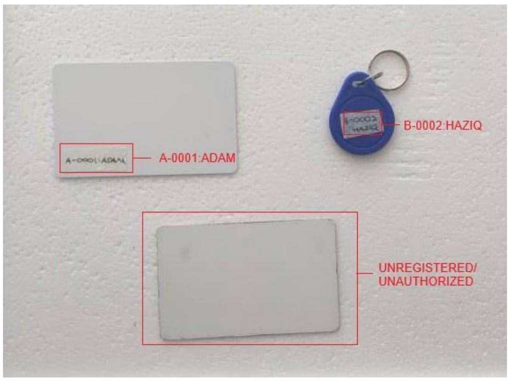

Figure 23: Registered RFIDs

3.2.2 Unique QR code identification of frozen products

Each frozen product is equipped with a unique QR code for identification and tracking purposes. The QR code is system-aligned and contains essential information about the product of a unique ID followed by the product's name, such as FT01-FishTofu and CC02-CrabChunk, as shown in Figure 24. This QR code serves as a crucial identifier for each product within the supply chain monitoring system, enabling accurate tracking throughout the transportation and supply process.

Figure 24: Unique QR code

3.3 Dashboard

The dashboard is a centralized interface for real-time monitoring and management of the system, providing key information and controls for stakeholders. It offers intuitive access to temperature readings, GPS coordinates, lock status, and other relevant data, both via web and mobile platforms.

3.3.1 Web dashboard

Authorized personnel can access the web dashboard through a browser interface to obtain real-time data and controls, facilitating monitoring and management of the system, as shown in Figure 25.

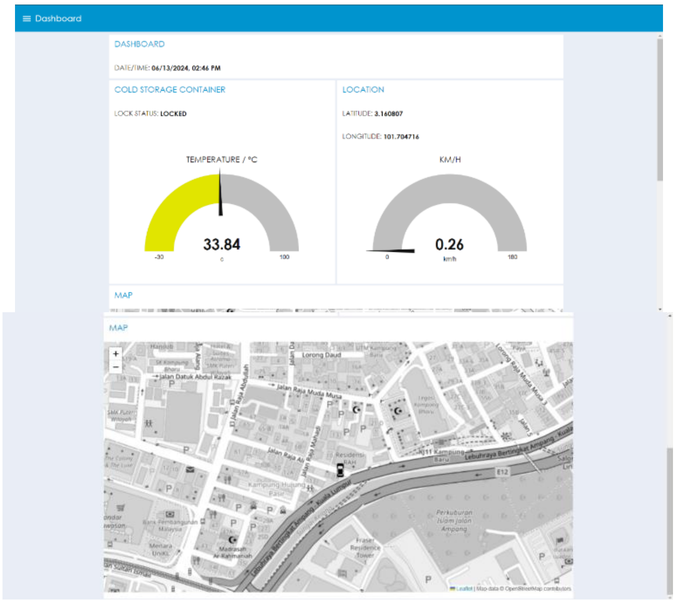

Figure 25: Web dashboard

3.3.2 Mobile dashboard

The mobile dashboard provides a streamlined, user-friendly interface for accessing system data remotely, as shown in Figure 26.

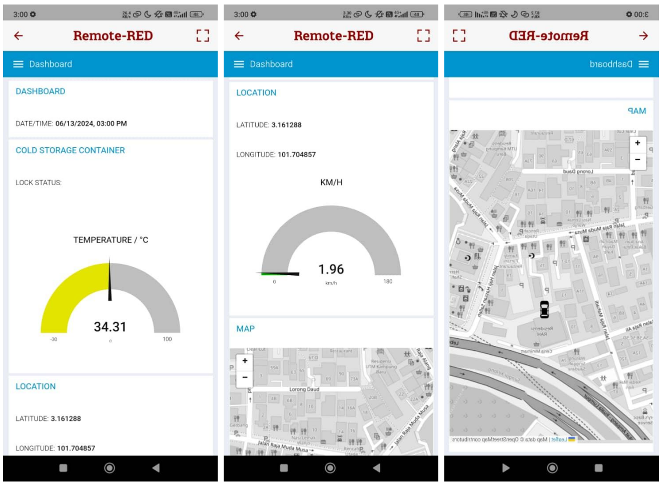

Figure 26: Mobile dashboard

3.3.3 Temperature gauge and lock status

The temperature gauge provides real-time visibility of the current temperature inside the container, allowing users to monitor temperature conditions effectively. It offers instant feedback on temperature variations, ensuring that the frozen products are stored within the desired range. Additionally, the lock state section indicates the status of the container lock, providing information on whether the container is securely locked or unlocked, as shown in Figure 27. This feature enhances security and ensures that the contents are properly protected during transit or storage.

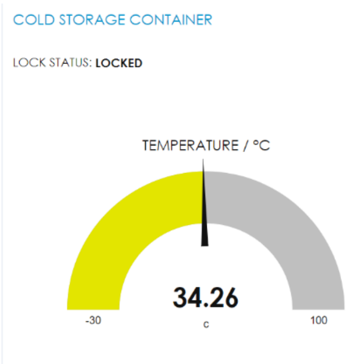

Figure 27: Temperature gauge and lock status

3.3.3.1 Alert System

The alert system plays a crucial role in notifying stakeholders of critical temperature conditions. When the temperature exceeds predefined thresholds set above -4°C, the system triggers an audio signal to alert users immediately, as shown in Figure 28 for the web dashboard and Figure 29 for the mobile dashboard. This ensures a timely response to temperature variations, helping to maintain the quality and integrity of the frozen products.

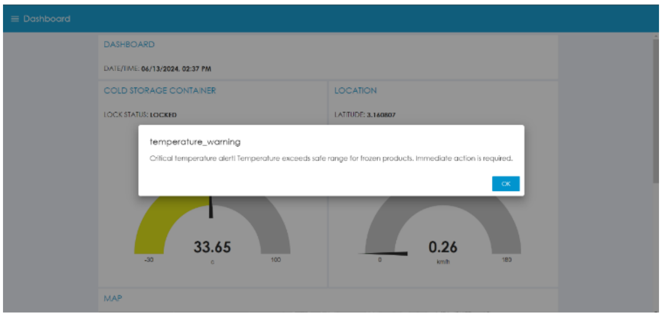

Figure 28: Web dashboard alert system

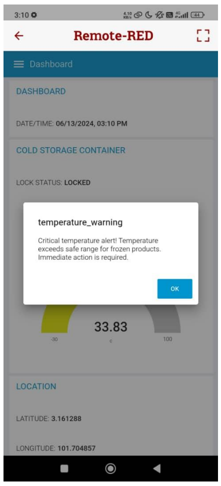

Figure 29: Mobile dashboard alert system

3.3.3.2 Access notification

Notifications of accessed worker IDs via RFID card are automatically generated and sent whenever there is a change in the lock state. Unauthorized attempts are also reported. This provides stakeholders with real-time updates on container security. Notifications appear at the top right corner of the web dashboard and the bottom of the mobile dashboard, as shown in Figure 30 for the web dashboard and Figure 31 for the mobile dashboard, Figure 32 shows examples of access notifications.

Figure 30: Web dashboard access notification

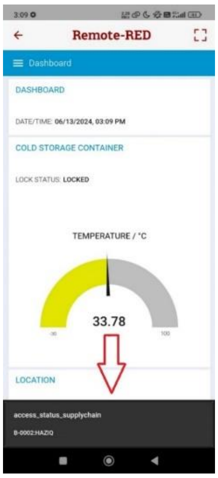

Figure 31: Mobile dashboard access notification

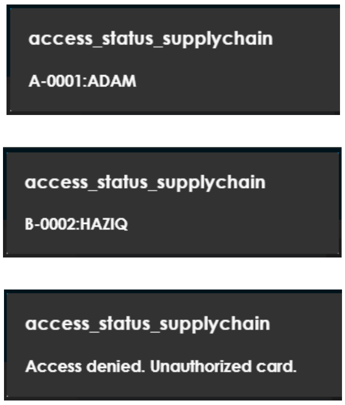

Figure 32: Examples of access notification

3.3.4 Location

The location feature tracks and displays the container's real-time location using GPS technology, providing essential information such as latitude, longitude, and speed in KM/H on the dashboard, as shown in Figure 33. Users can easily monitor the exact geographical position of the container at any given time, allowing for precise tracking throughout the supply chain journey. This functionality enhances logistics management by providing insights into the container's movement and ensuring timely deliveries.

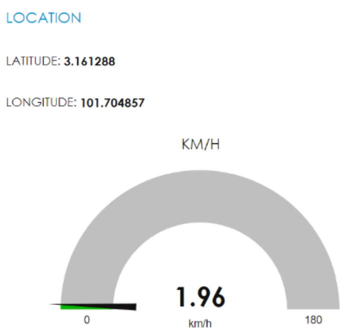

Figure 33: Dashboard of location

3.3.4.1 Map view

The map view feature enables zooming in and out for a more detailed view of street names and surrounding areas, benefiting not only logistics but also traffic management. As shown in Figure 34, It incorporates a car icon that indicates the transport location of the supply products, enhancing tracking and monitoring capabilities. With this feature, users can visualize the precise location of the container along its route.

Figure 34: Map view of location

3.3.5 Invoice tracking

The invoice section plays a crucial role in managing transaction details within the system. Workers can access the invoice form conveniently by clicking the three-line icon located at the top left corner of the dashboard interface, as shown in Figure 35. It includes product information, supplier names, receiver names, and timestamps for each transaction record, ensuring comprehensive documentation, as shown in Figure 36 for the web dashboard and Figure 37 for the mobile dashboard. This allows stakeholders to easily track product movement, identify responsible suppliers and receivers, and maintain accurate transaction records for auditing and analysis purposes.

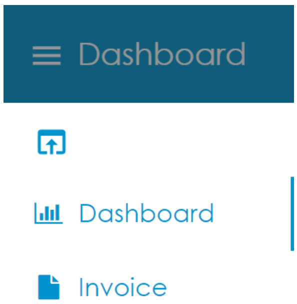

Figure 35: Accessing Invoice form

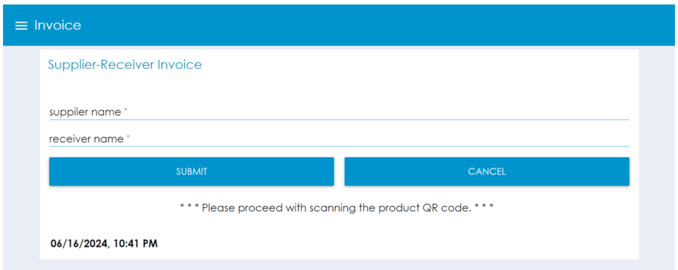

Figure 36: Web dashboard invoice form

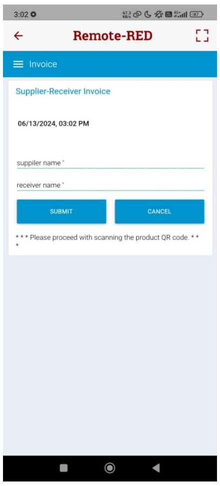

Figure 37: Mobile dashboard invoice form

3.3.5.1 Scanning product QR

To complete the invoice submission, product QR codes must be scanned with any device equipped with a QR scanner to update and verify inventory and invoice details, as shown in Figure 38. The confirmation output of invoice submission is displayed upon successfully scanning the product QR code, as shown in Figure 39. This feature streamlines inventory management and invoice processing, reducing manual errors and improving overall efficiency in supply chain operations.

Figure 38: QR scanning of product

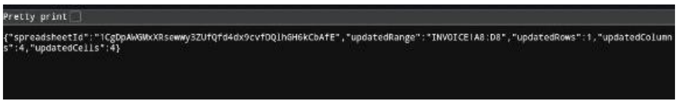

Figure 39: Successful scan and submission indicator for invoice

3.4 Database

The database system is fundamental in storing and managing the data generated by the IoT-Based Supply Chain of Frozen Food Monitoring system. It consists of two main databases, and all datasets are stored in cloud storage powered by Google. This cloud-based approach offers significant benefits, such as allowing stakeholders with authorized access to retrieve and interact with the database from anywhere. Additionally, cloud storage ensures data redundancy and reliability, reducing the risk of data loss due to hardware failures. It also provides automatic backups and updates, enhancing data security and integrity.

Data management is facilitated through Google Sheets, a powerful tool that simplifies data handling, sharing, and visualization. Google Sheets enables real-time collaboration, ensuring that stakeholders can work together efficiently and make informed decisions based on the most up-to-date information. The tool's integration with other Google services enhances its functionality, allowing for seamless data import and export, automated workflows, and customizable data views.

3.4.1 System database

The system database securely stores real-time data generated by the monitoring system, ensuring up-to-date information availability for stakeholders. The database is implemented using a CSV format managed through the Google Sheets platform. The primary data points injected into the database include:

•Timestamp:
Captures the exact time when the data was recorded.

•Temperature (°C):
Monitors the current temperature inside the container to ensure it remains within the required range for frozen products.

•Lock Status:
Indicates whether the container is locked or unlocked.

•Access Status:
Records the ID of the worker who accessed the lock, providing a traceable access log.

•GPS Data:
Includes latitude, longitude, and speed (KM/H) to track the real-time location and movement of the container.

Data is injected into the database every minute, ensuring continuous monitoring. However, if a worker accesses the system via RFID and toggles the lock, this action interrupts the regular one-minute interval, causing the data to be injected immediately. This mechanism ensures that any critical changes in the system's state are captured and recorded in real time, providing an accurate and up-to-date record of the system's operational status. This comprehensive data collection and storage approach supports effective monitoring and management of the supply chain.

	DATE / TIME	TEMPERATURE	LOCK STATUS	ACCESS STATUS	LATITUDE	LONGITUDE	SPEED
2	29/05/24 22:45	29.42	LOCKED	B-0002:HAZIQ	3.161942	101.705230	3.43
3	29/05/24 22:45	29.44	UNLOCKED	B-0002:HAZIQ	3.161942	101.705230	3.43
4	29/05/24 22:46	29.48	UNLOCKED		3.160531	101.704471	4.46
5	29/05/24 22:47	29.49	UNLOCKED		3.160418	101.704624	1.19
6	29/05/24 22:48	29.5	UNLOCKED		3.161148	101.704847	0.94
7	29/05/24 22:49	29.49	UNLOCKED		3.160430	101.704729	1.83
8	29/05/24 22:50	29.5	LOCKED	A-0001:ADAM	3.160753	101.704673	5.69
9	29/05/24 22:51	29.48	LOCKED		3.161836	101.705126	2.37
10	29/05/24 22:52	29.49	LOCKED		3.161534	101.705015	1.7
11	29/05/24 22:53	29.51	LOCKED		3.161490	101.704892	1.26
12	29/05/24 22:54	29.51	LOCKED		3.161262	101.704893	0.13
13	29/05/24 22:55	29.53	LOCKED		3.161259	101.704873	2.65
14	29/05/24 22:56	29.53	LOCKED		3.161543	101.704856	1.54
15	29/05/24 22:57	29.53	LOCKED		3.161502	101.704953	1.3
16	29/05/24 22:58	29.55	LOCKED		3.161362	101.704656	0.85
17	29/05/24 22:59	29.57	LOCKED	Access denied. Unauthorized card.	3.161627	101.705020	2.31
18	29/05/24 23:00	29.55	LOCKED		3.161579	101.704890	0.41
19	13/06/24 14:54	33.41	LOCKED		3.160807	101.704716	0.26
20	13/06/24 15:55	34.4	LOCKED		3.161288	101.704857	1.96

Figure 40: System database

3.4.2 Invoice tracking database

The invoice tracking database manages transaction details, including product information, supplier names, receiver names, and timestamps. It is designed to ensure data integrity and completeness by requiring all necessary input submissions from the invoice form before data is injected into the database. Specifically, it mandates the inclusion of the supplier's name, receiver's name, and product ID obtained from the QR scan. This requirement ensures that comprehensive transaction records are maintained, facilitating effective auditing and traceability of products throughout the supply chain. By ensuring that all relevant details are captured, the invoice database supports accurate and reliable transaction management.

	DATE / TIME	SUPPLIER	RECEIVER	PRODUCT
2	28/05/24, 22:10	ADAM	HAZIQ	0001Sausage
3	29/05/24, 22:52	JOHN	CENA	0022ChickenNugget
4	30/05/24, 18:05	IQMAL	IRFAN	0001Sausage
5	01/06/24, 15:42	ZIQRI	AFIQ	1002Ikan
6	05/06/24, 14:46	AIMAN	AZMI	FT01-FishTofu
7	05/06/24, 14:56	AFIQ	ROSLAN	CC02-CrabChunk
8	15/06/24, 14:24	RAHIM	JOJO	FT02-FishTofu

Figure 41: Invoice tracking database

3.5 Data analysis

The data analysis and dashboard are conducted using Tableau to visualize and interpret the collected data effectively.

3.5.1 Real-time temperature (per minute)

Figure 42 shows the analysis monitoring and visualizing minute-by-minute temperature readings in a line chart to detect any abnormalities and ensure optimal storage conditions for frozen products.

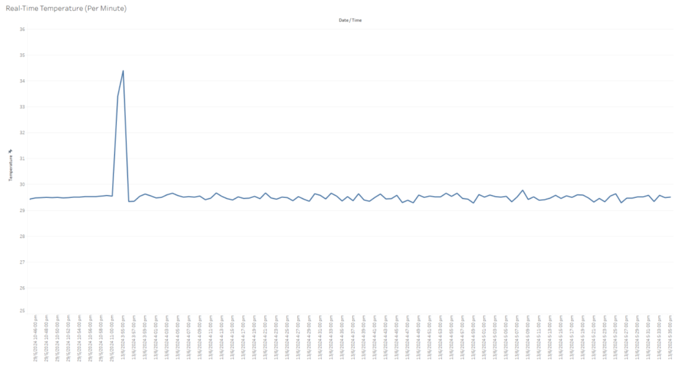

Figure 42: Real-time temperature (per minute)

3.5.2 Lock and access status analysis

Figure 43 analyses the tracking and display of the status of locks and access attempts, providing insights into security and access patterns.

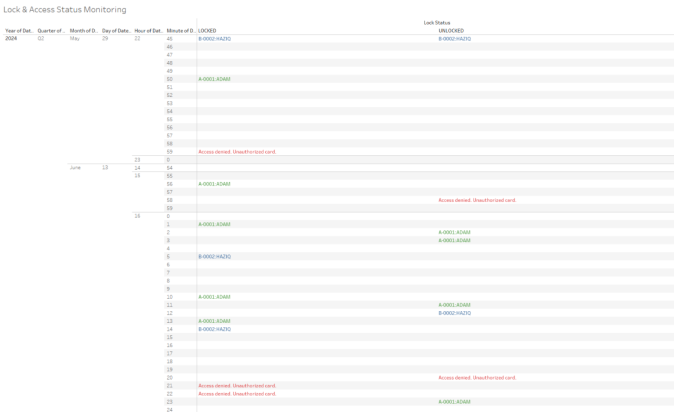

Figure 43: Lock and access status analysis

3.5.3 Location and speed analysis

Figure 44 displays the analysis of real-time location data in map view, monitoring the movement and speed in specific locations of the transportation unit to identify patterns and potential issues in transportation efficiency.

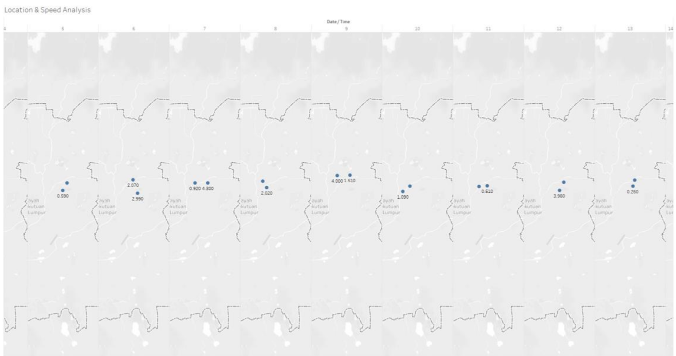

Figure 44: Location and speed analysis

3.6 Discussion of data analysis

Data analysis is critical in leveraging the collected information to enhance the frozen food supply chain's efficiency, reliability, and overall business performance. By examining the timestamp, temperature, lock status, access status, GPS data, and invoice data, valuable insights can be gained that drive informed decision-making and strategic improvements.

3.6.1 Timestamp analysis

The timestamp data provides precise logging of all recorded events and data points, allowing for detailed tracking of the system's operational timeline. This information is valuable for:

•Process Optimization:
Analyzing timestamps helps identify patterns and bottlenecks in the supply chain, enabling more efficient scheduling and resource allocation.

•Incident Tracking:
Timestamps allow for the exact timing of incidents, such as temperature breaches or unauthorized access, facilitating swift responses and corrective actions.

•Compliance Verification:
Ensuring adherence to regulatory and contractual timelines for handling and transporting frozen goods.

3.6.2 Temperature data analysis

Temperature data is crucial for maintaining the quality and safety of frozen food products. Analyzing this data provides insights into:

•Quality Control:
Monitoring temperature fluctuations helps ensure that products are stored and transported within the required temperature ranges, preserving their quality and safety.

•Predictive Maintenance:
Identifying trends in temperature data can indicate potential issues with refrigeration equipment, allowing for predictive maintenance and reducing the risk of spoilage.

•Regulatory Compliance:
Demonstrating adherence to temperature control regulations helps avoid penalties and builds trust with consumers and regulatory agencies.

3.6.3 Lock status analysis

Lock status data provides visibility into the security of the container, offering benefits such as:

•Security Management:
Tracking lock status ensures that containers remain secure during transit, reducing the risk of theft or tampering.

•Access Control:
Analyzing lock status changes helps identify unauthorized access attempts, enabling the implementation of stronger security measures.

•Operational Efficiency:
Ensuring that containers are promptly and securely locked and unlocked can streamline loading and unloading processes.

3.6.4 Access status analysis

Access status data records which personnel have accessed the system, providing valuable information for:

•Traceability:
Maintaining a log of who accessed the system and when enhances accountability and traceability, important for both internal audits and regulatory compliance.

•Workforce Management:
Analyzing access data can help optimize workforce deployment by understanding access patterns and workload distribution.

•Security Enhancement:
Identifying patterns in access data can highlight potential security vulnerabilities and inform improvements in access control protocols.

3.6.5 GPS data analysis

GPS data provides real-time location tracking of the transportation or container, offering several business advantages:

•Route Optimization:
Analyzing GPS data helps identify the most efficient routes, reducing transportation time and fuel costs.

•Real-Time Tracking:
Providing stakeholders with real-time location updates enhances transparency and enables proactive issue resolution, such as rerouting in case of delays.

•Delivery Verification:
GPS data confirms delivery times and locations, helping resolve disputes and ensuring timely deliveries.

3.6.6 Invoice data analysis

Invoice data, including supplier names, receiver names, and product IDs, provides critical information for managing transactions and inventory. Analyzing this data offers several benefits:

•Transaction Verification:
Detailed records of supplier and receiver names ensure that each transaction is properly documented and can be verified.

•Inventory Management:
Tracking product IDs helps maintain accurate inventory records, preventing shortages or overstock situations.

•Audit and Compliance:
Detailed transaction records support audits and compliance with financial regulations, ensuring transparency and accountability in supply chain operations.

3.6.7 Integrative insights

By combining and analyzing these diverse data sets, more valuable comprehensive insights can be gained:

•End-to-End Visibility:
Integrating timestamp, temperature, GPS, and invoice data offers a complete view of the product's journey, ensuring all aspects of the supply chain are functioning optimally.

•Anomaly Detection:
Correlating temperature breaches with lock and access data can help pinpoint the cause of issues, such as identifying if a temperature spike occurred due to the container being unlocked for an extended period.

•Performance Metrics:
Aggregating data over time allows for the calculation of key performance indicators (KPIs), such as average delivery time, temperature compliance rates, and security breach incidents, which are crucial for continuous improvement efforts.

4. CONCLUSION

4.1 Introduction

The development and analysis presented in this thesis demonstrate the successful implementation and potential of the IoT-Based Supply Chain of Frozen Food Monitoring system. Through the project, a prototype system was designed and evaluated, encompassing various components such as temperature monitoring, access control, location tracking, and transaction management. The system's dashboard provides real-time insights, enhancing visibility and control over the supply chain process. Achieving the project objectives confirms the system's capability to improve efficiency and quality assurance in the frozen food industry.

4.2 Summary of findings

The findings indicate that the system effectively monitors temperature, manages access control, tracks location, and handles transaction records. The integration of IoT technologies offers valuable real-time insights into supply chain operations.

4.3 Achievement of project objectives

The project successfully achieved its goals of developing a prototype system for monitoring frozen food supply chains in real time. The system provides features for temperature monitoring, access control, location tracking, and transaction management, aligning with the project objectives.

4.4 Key results and observation

Key results demonstrate the system's ability to improve supply chain visibility, ensure product quality, and optimize operational efficiency. Observations highlight the system's reliability and potential for enhancing overall supply chain management.

4.5 Implications and applications

The implications of this project extend to various industries, particularly those involving perishable goods transportation. The system's applications include improving inventory management, ensuring compliance with quality standards, and enhancing customer satisfaction.

4.6 Limitations and future work

Despite its successes, the system faces limitations such as dependency on stable connectivity and the need for periodic maintenance. Future work could focus on addressing these limitations, expanding the system's scalability, and integrating advanced analytics for predictive maintenance and optimization.

4.7 Conclusion

In conclusion, the IoT-Based Supply Chain of Frozen Food Monitoring system offers significant potential for revolutionizing supply chain management in the frozen food industry. By providing real-time monitoring, control, and insights, the system can enhance efficiency, quality, and customer satisfaction. Continued research and development in this area are essential for realizing the full benefits of IoT technology in supply chain management.

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